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Effect of Recycling Thermophilic Sludge on the Activated Sludge Process

Metropolitan Water Reclamation District of Greater Chicago, IL

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T.B.S. Prakasam, S. Soszynski, D. R. Zenz,
C. Lue-Hing, L. Blyth, and G. Sernel

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16. ABSTRACT

A full-scale investigation was undertaken at Chicago's Hanover Park Water Reclamation Plant (WRP) to study whether the net sludge production from the WRP could be reduced by implementing a scheme developed by W. Torpey et al. (1984). In this process, sludge is withdrawn from a thermophilic digester operated in series with a mesophilic digester and partially recycled into the aeration tanks of the activated sludge system.

The Hanover Park WRP, which has a design flow capacity of 45,420 million m^3 per day (12 mgd), was split into a control section and an experimental section. The two sections were operated similarly except the thermophilic drawoff was recycled into the aeration tanks of the experimental section from a digester system consisting of mesophilic and thermophilic digesters operated in series.

A reduction in net sludge production of about 10 percent was achieved at 40 percent recycle of thermophilic sludge into the aeration tanks at the Hanover Park WRP. This was a much smaller reduction than obtained by Torpey et al. Sludge dewatering properties were not improved. The recycling produced no adverse effects on quality of the treated wastewater.

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T.B.S. Prakasam, S. Soszynski, D.R. Zenz,
C. Lue-Hing, L. Blyth, and G. Sernel
Metropolitan Water Reclamation District
of Greater Chicago
Chicago, Illinois 60611

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Project Officer
Joseph B. Farrell
Water and Hazardous Waste Treatment Research Division
Risk Reduction Engineering Laboratory
Cincinnati, Ohio 45268

RISK REDUCTION ENGINEERING LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing of research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This report presents the results of an investigation conducted at the Hanover Park Water Reclamation Plant (WRP), Hanover Park, Illinois, operated by the Metropolitan Water Reclamation district of Greater Chicago (District). The main objective of this study was to evaluate on a full scale whether it would be feasible to achieve a significant reduction in sludge production by retrofitting an existing activated sludge system with a mesophilic-thermophilic (M-T) digestion scheme and recycling the drawoff from the thermophilic digester into the aeration tanks of the activated sludge system. The Hanover Park WRP was divided into control and experimental sections. The experimental section was operated by employing the M-T digestion scheme and recycling the thermophilic digester drawoff, whereas the control section was operated as a conventional activated sludge system with high rate mesophilic digestion of the sludge produced. Although the results reported by other investigators, who employed a similar scheme showed reductions in sludge ultimately discharged by as much as 50 percent, this study did not confirm such reductions.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

ABSTRACT

A full-scale investigation was undertaken at the Hanover Park Water Reclamation Plant (WRP) operated by the Metropolitan Water Reclamation District of Greater chicago to study whether the net sludge production from the WRP can be reduced by implementing a scheme reported by Torpey et al. (1984). This scheme involved the recycling of sludge withdrawn from a thermophilic digester, operated in series with a mesophilic digester, into the aeration tanks of an activated sludge system.

The Hanover Park Water Reclamation Plant (WRP), which has a design flow capacity of 45,420 million m^3 per day (12 mgd), was split into a control section and an experimental section. The control and experimental sections were operated as nitrifying activated sludge systems, with the exception that thermophilic drawoff was recycled into the aeration tanks of the experimental section from a digester system consisting of mesophilic and thermophilic digesters operated in series.

In contrast to the results reported by Torpey et al., a significant reduction in the net sludge production was not observed as a consequence of incorporating the recycling of thermophilic sludge into the aeration tanks of the Hanover Park WRP.

This report was submitted in fulfillment of Cooperative Agreement No. CR-811925-01-8 by the Metropolitan Water Reclamation District of Greater Chicago under the sponsorship of the U.S. Environmental Protection Agency. The experimental program covers a period of October 1984 to August 1988. The final report was submitted in June 1989.

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SECTION 1

INTRODUCTION

Sludge treatment and disposal costs, in general, are proportional to the volume and quantity of the sludge produced in a sewage treatment facility. In 1987 alone, the Metropolitan Water Reclamation district of Greater Chicago (District) disposed of or utilized 251,386 metric tons (276,525 short tons) of dry sludge solids produced at its seven sewage treatment facilities. The District has been constantly pursuing a policy of keeping abreast with the advances made in the field of sludge treatment and disposal technology, in order to minimize its sludge processing and disposal costs. Besides investigating procedures that reduce sludge conditioning and dewatering costs, and hence overall sludge disposal costs, the District constantly evaluates its solids processing procedures to optimize its operations and treatment costs.

The use of any technology or changes made in the operation of a treatment facility, which reduce the quality and volume of sludge, should result in a reduction of the cost of sludge treatment and disposal. Among the possibilities that exist, improved methods of sludge digestion and dewatering are usually pursued to achieve reductions in sludge quantities and volume.

A novel approach for reducing sludge production has been reported by Torpey, et al., (1984). They reported on a new process developed at the Rockaway Sewage Treatment Plant, operated by the New York Department of Environmental Protection. This process consists of a scheme in which sludge from a mesophilic digester is processed through a thermophilic digester and then a portion of the thermophilic digester drawoff is recycled through the aeration tanks of an activated sludge system. The remainder of the thermophilic drawoff is passed through a rethickening and elutriation tank. By this approach, these authors reported that the volume and quantity of the sludge in comparison to that produced by the activated sludge plant incorporating mesophilic digestion with no recycle was reduced by about 60 percent. They hypothesized that this reduction in sludge quantity was possible due to the additional destruction of solids achieved by subjecting mesophilically digested sludge solids to thermophilic digestion and by oxidizing some of the solids contained in the thermophilic sludge by recycling it to the aeration tanks of an activated sludge system. These authors stated that an examination of the data published by Kraus (1945, 1946) also showed a large reduction in volatile solids. In his studies, Kraus recycled sludge from a mesophilic digester to an activated sludge plant to control sludge bulking caused by repeated discharges of a waste containing high carbohydrates.

Exposure of sludge solids to different environmental conditions e.g., alternating aerobic and anaerobic conditions, is known to achieve a reduction in the quantity of solids produced in other studies as well. Cohen and Puntenney (1973) achieved significant stabilization of aerobically digested sludge when incubated with anaerobic organisms.

Mesophilic digestion of primary and waste-activated sludge is a well established practice in the United States. However, thermophilic digestion of sludge is not a well accepted practice in this country although several advantages are claimed for this process. These advantages include increased rates of sludge loading per unit volume of digester capacity, pathogen destruction, and increased dewaterability. There are some disadvantages associated with the thermophilic digestion process. Additional energy is required for sludge heating, and there is a need for increased attention to temperature control. The process can have possible odor nuisances due to increased volatile acid production, and can produce increased dissolved solids and ammonia concentration in the liquid steams from sludge dewatering operations.

In a recently reported study, Carrio, et al., (1985) discussed the results of the performance of several treatment plants operated by the New York Department of Environmental Protection, where in-plant modifications were made to achieve a reduction in their sludge production. In the Bowery Bay Water Pollution Control Plant, which is a step-aeration plant, recirculation of digested sludge directly to the aerators resulted in a sludge mass reduction of 16 percent. The recirculation of digested sludge to either the aerators or to the thickener of the Newton Creek Water Pollution Control Plant, which is a modified aeration plant, resulted in a sludge mass reduction of 41 percent. A similar mass reduction was also reported for the 26th Ward facility. In contrast, there was an increase of approximately 10 percent in sludge mass at the Oakwood Beach facility when 50 percent of the digested sludge was recycled to the head-end of the plant, although a volume reduction of 22 percent was achieved.

Using a process of mesophilic digestion followed by thermophilic digestion and recycling 50 percent of the digested thermophilic drawoff to the aeration tanks and subjecting the remainder to elutriation and rethickening, Carrio, et al., (1985) reported that sludge quantity and volume were reduced by about 67 and 50 percent, respectively. Although they reported that 67 percent of the dry solids were destroyed, a recomputation of their data indicated that it was in actuality 47 percent; perhaps this was a typographical error.

Except for the results of the studies conducted by Torpey, et al., and Carrio. et al., at the New York City treatment plants, information is not available on the performance of an activated sludge plant which has incorporated a scheme involving the recycling of sludge from a mesophilic-thermophilic (M-T) sludge digestion system into its aeration tanks.

Other similar full-scale treatment plant data are not available to corroborate the results obtained at the New York City treatment plant, where thermophilic digestion of sludge was practiced in conjunction with mesophilic digestion. Also, the results of the New York City's treatment plants were not obtained under controlled conditions. The effect of recirculating digested sludge, which was produced under mesophilic or mesophilic followed by thermophilic digestion to aeration tanks was not investigated with appropriate controls in the New York City's studies.

The District operates several treatment facilities and manages a large quantity of sludge solids. It was felt that it would be useful to conduct a full-scale study under controlled conditions to investigate whether the results reported by Torpey et al., (1984) and Carrio et al., (1985) could be reproduced at the District's treatment facilities. If sludge production could be reduced substantially by in-plant modifications as described by the above authors, it would reduce the quantities of sludge to be disposed and hence help reduce the overall sludge disposal costs. Thus, there could be a tremendous benefit at the national level if sludge quantities could indeed be reduced by process modifications as those implemented in the New York City's sewage treatment facilities.

In view of the foregoing considerations, the District with the assistance of a grant from the United States Environmental Protection Agency (USEPA) undertook a demonstration study at its Hanover Park Water Reclamation Plant (WRP) by retrofitting its activated sludge system with a M-T digestion scheme to investigate the various pros and cons of the effects of incorporating such a scheme. The scheme reported by Torpey, et al., (1984) and Carrio, et al., (1985), if workable, could contribute to the state-of-art of sludge treatment and disposal technology, provided there is no detrimental effect on the efficiency of the activated sludge system due to the recycling of thermophilic sludge drawoff.

The following are the main objectives of the study conducted at the Hanover Park WRP:

1. To demonstrate on a full-scale whether the retrofitting of an existing activated sludge system with a mesophilic-thermophilic (M-T) digestion scheme and

   recycling the drawoff from the thermophilic digester into the aeration tanks

   activated sludge system would cause a reduction in the volume and quantity of volatile solids produced as compared to the volume and quantity of volatile solids produced from a conventional activated sludge system using mesophilic digestion and no recycling of digested sludge.

2. To evaluate the quality of the effluents obtained under the various phases of the M-T digestion scheme and compare the same with the results obtained under the conventional mode of operating an activated sludge system.

3. To determine the dewatering characteristics of the sludges resulting from the recycling of thermophilic digester drawoff and compare them with those of the drawoff derived from a conventional mesophilic digester.

4. To evaluate the odor characteristics of the sludge derived from the M-T digester sequence and compare them with those of the mesophilic digester drawoff.

5. To compare the removal of heavy metals observed in a conventional activated sludge system with the removal observed using the recycle of the sludge from the M-T digestion scheme.

SECTION 2

SUMMARY AND CONCLUSIONS

A full-scale demonstration study was undertaken at the Hanover Park Water Reclamation Plant (WRP) to investigate whether the incorporation of a scheme involving the recycling of the drawoff from a thermophilic digester into the aeration tanks of an activated sludge system would result in a net reduction in sludge production in comparison to a conventional activated sludge system where such recycling is not practiced. The Hanover Park WRP was divided into control and experimental sections. The control section was operated as a conventional activated sludge system with mesophilic digestion (35°C) of the primary and waste activated sludge in two digesters operated in series. The experimental section was operated similarly, with the exception that the primary and waste activated sludge produced from it were digested in a mesophilic digester followed by a thermophilic digester. The thermophilic sludge withdrawn was recycled at various proportions into the aeration tanks of the experimental section at different times to determine whether the net sludge production from this section was lower than that produced in the control section as was reported by Torpey et al., (1984) and Carrio et al., (1985) due to the loss of volatile solids. In addition, the quality of the effluents produced, the dewaterability characteristics of mesophilic and thermophilic sludge drawoffs, the fate of heavy metals in the control and experimental section digesters, and the odor characteristics of the sludges produced were also studied. The following are the conclusions from this study.

FATE OF VOLATILE SOLIDS

1. About two to five percent more volatile solids destruction was observed in the experimental section digesters than in the control section's mesophilic digesters, when thermophilic sludge drawoff was recycled (up to 40 percent of the volume withdrawn) into the aeration tanks of the experimental section. When the thermophilic sludge drawoff recycle rate was increased to the aeration tanks to about 50 percent of the volume withdrawn, the volatile solids destruction in the experimental section digesters was found to be lower by about 12.5 percent than that observed in the control section digesters.

2. A volatile suspended solids (VSS balance around the aerator-clarifier revealed a net VSS production for both control and experimental systems.

Scatter was too great to allow a quantitative conclusion about the influence rate on VSS production.

3. Comparison of masses of VSS in the waste activated sludge (WAS) streams from control Battery B and experimental Batteries C and D showed that recirculation of up to 40 percent of the meso-thermophilically digested sludge did not increase the mass of (WAS) per unit volume of wastewater treated.

4. The difference in the sludge ultimately disposed from the control and experimental sectioins is not statistically significant. Results by other authors (1,5) showing reductions in sludge discharged by as much as 50 percent have not been confirmed. A possible explanation is the high sludge retention time, 18d, in this study compared to less than 6d in the other investigations.

EFFLUENT QUALITY AND PLANT PERFORMANCE

1. The overall performance of the control and experimental sections of the Hanover Park WRP was comparable during all the phases of the study. The recycling of thermophilic sludge drawoff even at the rate of about 50 percent of the volume withdrawn from the digester into the aeration tanks of the experimental section did not seem to have an adverse effect on the secondary effluent quality.

2. The overall BOD removals of the control and experimental sections were comparable and were in the range of 91.7 to 97.2 and 94.2 to 97.7 percent, respectively, during the various phases of the study. The corresponding secondary effluent BOD values were in the range of 3 to 9 and 3 to 6 mg/L, respectively, for these sections. Recycling of up to 50 percent thermophilic sludge evidently had no noticeable effect on BOD removal.

3. The overall suspended solids removal in the control and experimental sections were in the range of 83.9 to 94.2 and 89.4 to 94.7 percent, respectively. The secondary effluent suspended solids concentration in these sections were comparable and were in the ranges of 6 to 15 mg/L (control) and 5 to 10 mg/L (experimental). Again recycling of digested sludge had no noticeable effect on percent removal.

4. The percent removal of NH_4-N was within the range of 91.0 to 98.6 percent in the control and experimental sections. The NH_4-N concentration of the secondary effluent was less than 1.2 mg/L in both of these sections indicating that the recycling of thermophilic sludge did not have an adverse effect on nitrifiction.

5. The recycling of thermophilic sludge drawoff into the aeration tanks of the experimental section did not have a discernible influence on the SVI values of the mixed liquors. However, there was too much scatter in SVI values for any firm conclusions on the effect of recyclling.

6. A comparison of the mixed liquor dissolved oxygen concentration and oxygen uptake rate data for the control and experimental section aeration tanks revealed no significant trends. Scatter in the results prevented drawing any firm conclusions on the effect of recycling on these variables.

7. The recycling of thermophilic sludge into the aeration tanks of the experimental section did not seem to alter the microbiological profile of the mixed liquor when compared to the same of the mixed liquor of the control section aeration tanks.

8. The soluble concentration of Zn, Cd, Cu, Cr, Ni, Pb, and Hg remained approximately the same in the digester feeds and draws indicating that no significant solubilization of these metals occurred during mesophilic or thermophilic digestion. However, the soluble concentration of iron in the digester feed of the control and experimental sections decreased significantly in the primary digester as it underwent digestion. No further resolubilization of this metal occurred in the secondary digesters.

DEWATERABILITY AND OTHER CHARACTERISTICS OF MESOPHILIC AND THERMOPHILIC SLUDGE

1. Capillary Suction Time (CST) measurements at various polymer dosages indicated that mesophilic sludge required a lower polymer dosage than the thermophilic sludge (10 vs. 22.5 kg/dt) to achieve the

minimum CST that was possible. However, the thermophilic sludge exhibited a higher floc strength than the mesophilic sludge.

2. Pilot scale centrifuge studies confirmed that the thermophilic sludge required a higher polymer dosage than the mesophilic sludge. At optimum polymer dosages, these studies also indicated that the mesophilic sludge approached 100 percent solids capture whereas the thermophilic sludge approached a maximum of 96 percent solids capture. The lower solids capture rate with thermophilic sludge was probably due to the higher concentration of fine particles in it than in the mesophilic sludge.

3. The percent cake solids achieved in pilot-scale centrifuge studies appeared to be similar at any given polymer dosage for the mesophilic and thermophilic sludge.

4. Numerous complaints about unpleasant odors were received from homes near the sludge farm during the experimental program as contrasted to practically no complaints when only mesophilically digested sludge was being discharged. The odor of thermophilically digested sludge evidently was either more offensive or more identifiable than the odor of mesophilically digested sludge.

INTEGRATED CONCLUSIONS

1. The recirculation of meso-thermophilically digested sludge to the activated sludge aerator caused a minor reduction in sludge mass discharged at Chicago's Hanover Park Water Reclamation Plant. Recirculation rates over 40 percent overloaded the digesters. There were no adverse effects on quality of treated wastewater. Based on lack of any significant advantages, use of this process at Hanover Park is not appropriate.

2. The objectionable odor of the thermophilically digested sludge caused so many complaints that use of this process as the terminal digestion step is ill-advised if sludge is to be utilized on farmland with close neighbors.

SECTION 3

METHODS AND MATERIALS

METHOD OF APPROACH

The method of approach to this study consisted of carrying out full-scale investigations at the Hanover Park WRP in various phases. A description of the Hanover Park WRP, its modification in order to conduct this study, and the characteristics of the various phases are described below.

Description of the Hanover Park WRP

An aerial view of the Hanover Park WRP is given in Figure 1 and a schematic of the same is given in Figure 2. The normal mode of operation in the digestion section of the plant is shown by the lines; the solid lines for this section show the arrangement during the experimental program.

The WRP is located near the intersection of Barrington Road and Irving Park Road (Route 19) in the village of Hanover Park, Illinois. The plant treats the wastewater from a 31-square kilometer (12-square miles) area which includes portions of five villages in the Northwestern part of Cook County. This WRP was chosen as the best operated Class A wastewater treatment plant in the State of Illinois in 1980 and 1988. It also received in 1981, 1985, and 1986, a Certificate of Excellency Award in wastewater safety from the Illinois Environmental Protection Agency.

During dry weather, all sewage entering the WRP is fully treated. Under wet weather flow conditions, incoming storm water can be pumped at a rate of up to 190,000m^3 per day (50 mgd) into storage ponds where it is temporarily stored until it can be returned for complete treatment during dry weather flow conditions.

After entering the WRP, sewage flows through coarse screens. The two units of inclined bar screens are 0.91m (3 feet) wide and are set 3.05m (10 feet) deep into the influent channel and have 5.1cm (2 inches) openings. The screening are collected by power driven rakes which move across the bars and are discharged to hoppers. Screenings are removed by a scavenger service and taken to an approved landfill for disposal.

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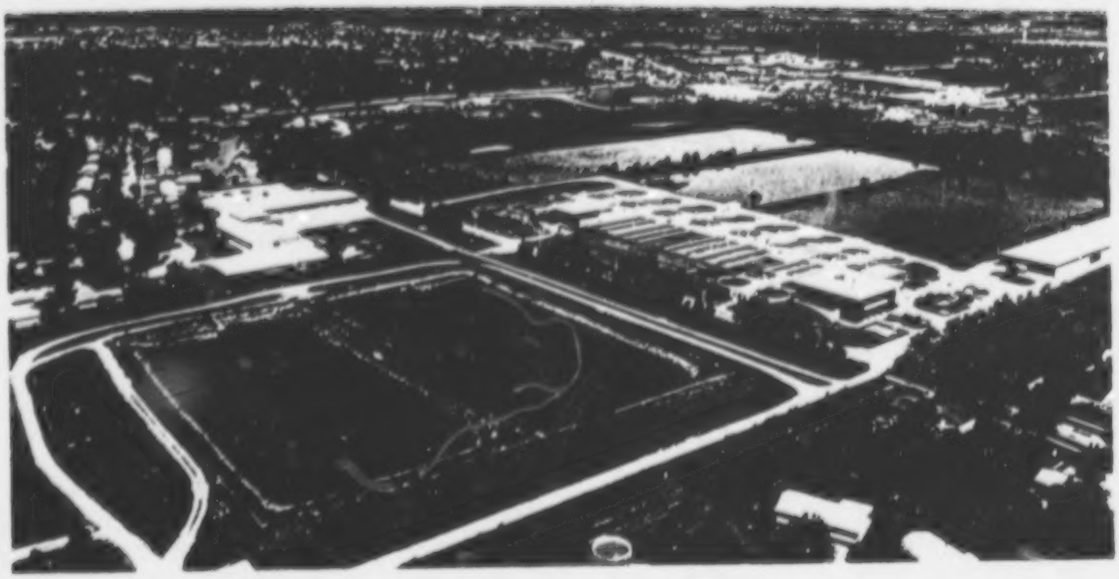
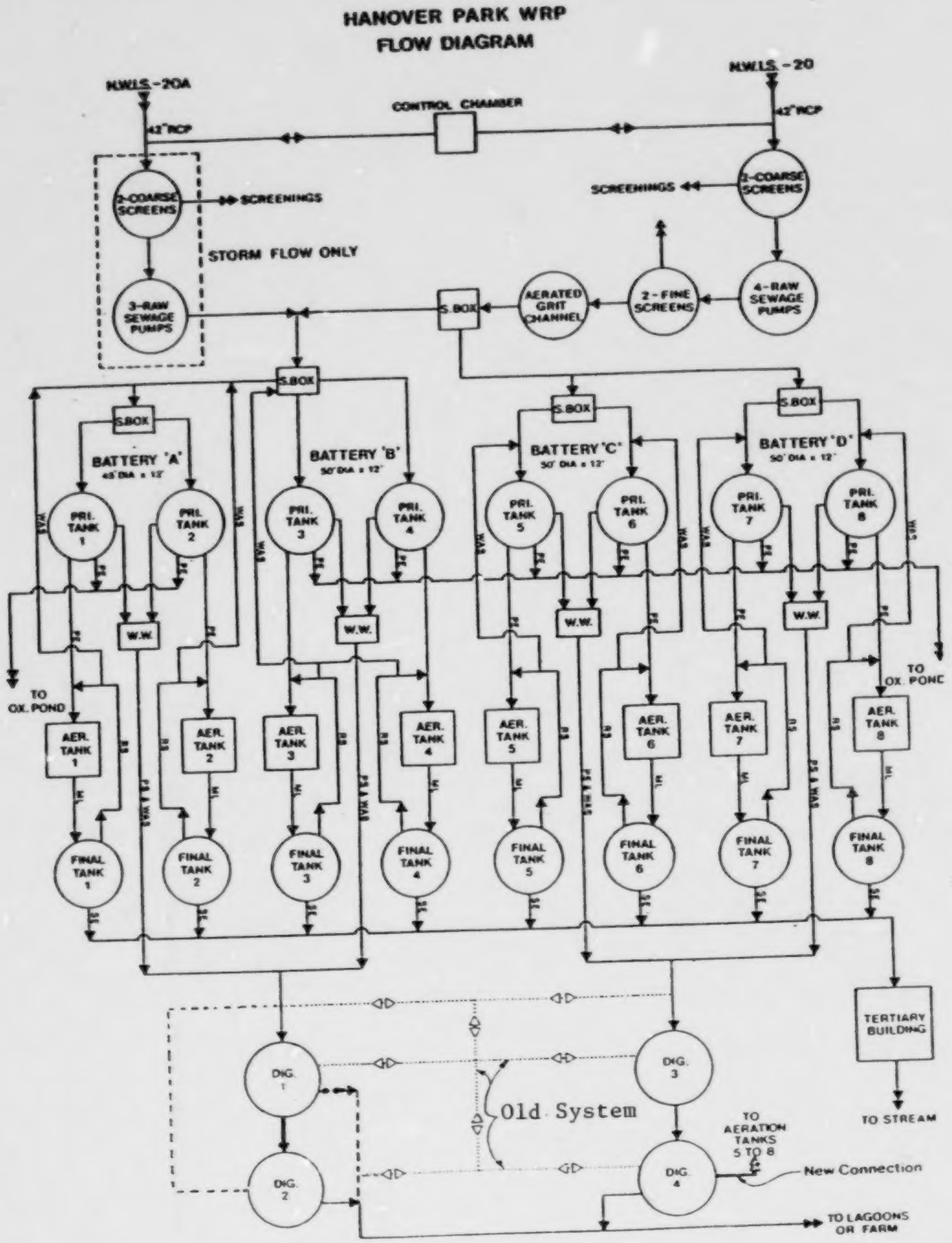


FIGURE 1. AERIAL VIEW OF THE HANOVER PARK WATER RECLAMATION PLANT


HANOVER PARK WRP
FLOW DIAGRAM
N.W.I.S.-20A
N.W.I.S.-20
42" RCP
42" RCP
CONTROL CHAMBER
2-COARSE SCREENS
SCREENINGS
STORM FLOW ONLY
3-RAW SEWAGE PUMPS
2-COARSE SCREENS
SCREENINGS
4-RAW SEWAGE PUMPS
2-FINE SCREENS
AERATED GRIT CHANNEL
S.BOX
BATTERY 'A' 45' DIA x 12'
BATTERY 'B' 50' DIA x 12'
BATTERY 'C' 50' DIA x 12'
BATTERY 'D' 50' DIA x 12'
PRI. TANK 1
PRI. TANK 2
PRI. TANK 3
PRI. TANK 4
PRI. TANK 5
PRI. TANK 6
PRI. TANK 7
PRI. TANK 8
W.W.
WAS
P.E.
P.S.
R.S.
ML
S.E.
P.S. & WAS
TO OX. POND
TO OX. POND
AER. TANK 1
AER. TANK 2
AER. TANK 3
AER. TANK 4
AER. TANK 5
AER. TANK 6
AER. TANK 7
AER. TANK 8
FINAL TANK 1
FINAL TANK 2
FINAL TANK 3
FINAL TANK 4
FINAL TANK 5
FINAL TANK 6
FINAL TANK 7
FINAL TANK 8
TERTIARY BUILDING
TO STREAM
DIG. 1
DIG. 2
DIG. 3
DIG. 4
Old System
TO AERATION TANKS 5 TO 8
New Connection
TO LAGOONS OR FARM

Notation:
N.WIS. 20,20A: Northwest Interceptor Sewers; W.W: Wet Well; S.BOX: Splitter Box; P.S.: Primary Sludge; WAS: Waste Activated Sludge; R.S.: Returned Sludge; ML: Mixed Liquor; P.E.: Primary Effluent; S.E.: Secondary Effluent; OX. POND: Oxidation Pond.

FIGURE 2. SCHEMATIC OF HANOVER PARK WRP

Raw sewage pumps lift the incoming sewage to the fine screens where the sewage then flows by gravity through the remaining treatment processes. There are eight vertical raw sewage pumps having a total pump capacity of 190,000m^3 per day (50 mgd) with 630 total installed horsepower.

Following pumping, the raw sewage is passed through fine screens (two parallel units) to remove solid materials larger than 1.59cm (5/8th inch). This operation removes solid material that would decrease efficiency in the aerated grit chambers and the treatment processes which follow fine screening. Description and operation of the fine screens is identical to that of the coarse screens. Fine screenings are removed by a scavenger service and taken to an approved landfill for disposal.

The sewage then flows to two aerated grit chambers with flight-type grit removal units. Each grit chamber is rectangular in shape, approximately 3.175m (10ft. 5in.) wide by 10.57m (34ft. 8in.) long with bottoms sloping toward a collection trough which runs the entire length of the chamber. The water depth is approximately 3.4m (11 ft. 2in.). Low pressure air is distributed within each tank by air headers along the length of the tank. Horizontal velocity through each grit chamber is 2.44cm per second (0.08 ft/sec) at plant design capacity. Grit which settles to the bottom of the chamber is carried by a flight type grit collector to a collection pit at the influent end of the tank. From this point, the grit is pumped to a grit washer which dewaters the grit and the dewatered grit is then conveyed to a hopper. Grit is removed by a scavenger service and taken to an approved landfill for disposal.

Primary Treatment--

Effluent from the grit chambers flows by gravity to eight circular primary settling tanks which physically settle out approximately 40 percent of the solids remaining in the sewage. Each tank is equipped with an automatic overflow weir discharging excess flow to the open storage ponds, except that primary tanks 1 and 2 discharge their excess flow directly into the secondary conduit. Influent enters the tank through the center influent well and flows radially outward to the tank periphery. At the tank periphery, the effluent flows over fixed weirs. Solids settling to the floor of the tank are scraped by mechanically driven plows at the bottom of the tank to a sump located near the influent weir. The primary sludge which settles out is fed to the sludge digesters. Scum which floats to the surface is collected by skimmers from which it is pumped to the scum concentration tank in the pretreatment building.

There are two primary settling tanks for each aeration battery. The primary settling tanks associated with Battery A are 13.72m (45 ft.) in diameter. The six primary settling tanks associated with Batteries B, C, and D are 15.24m (50 ft.) in diameter. All the settling tanks have a depth of 3.66m (12 ft.). They are designed for flows between 3,785 to 7,570 m^3 per day (1 to 2.0 mgd) each and 3.4 to 2.1 hrs. detention times.

Secondary treatment--

Effluent from the eight primary settling tanks flows to eight two-pass aeration tanks. Low pressure air is provided through diffuser plates of varying permeabilities. Two aeration tanks comprise a battery. Battery A is the oldest battery and the two aeration tanks contained in it are each 3.96m (13 ft.) deep, 6.4m (21 ft.) wide, and 21.34m (70 ft.) long per pass. Batteries B, C, and D are identical, and each of the aeration tanks in these batteries is 3.96m (13 ft.) deep, 7.6m (25 ft.) wide, and 32m (105 ft.) long per pass. The primary effluent is mixed with adjustable portions of return activated sludge in the aeration tanks. The required air flow rate is automatically controlled by dissolved oxygen sensors.

Four aeration units (Batteries C and D) are designed for a primary influent flow of 5,678 m^3 per day (1.5 mgd) each with an eight-hour detention time. Two aeration units each are designed for a primary influent flow of 7,570 m^3 per day (2.0 mgd) with a six-hour detention time (Battery B), and two aeration units each are designed for a flow of 7,785 m^3 per day (1.0 mgd) with a seven-hour detention time (Battery A).

The effluent from each aeration tank (mixed liquor) then flows to its respective circular final settling tank. There are a total of eight tanks designed to separate settled solids (sludge) from the mixed liquor. There are six 18.23m (65 ft.) and two 12.19m (40 ft.) diameter tanks with a depth approximately 3.66m (12 ft.). They are designed for flows of between 3,785 m^3 and 7,570 m^3 per day (1 and 2 mgd) with surface settling rates of 18.41 to 30.96 $m^3/m^2.d$ (452 to 760 gal/ft^2/day). The final settling tanks serving Battery B are peripherally fed, whereas the rest are centrally fed. Scum collection in these tanks is identical to that in the primary tanks, except that the final tanks connected to Battery A do not have a scum removal system. Solids settling to the bottom of these tanks are removed by scraper mechanisms and then are either returned to the aeration tanks to be mixed with primary tank effluent, or are wasted to primary clarifier contents. Effluent from the final settling tanks flows over fixed weirs at the tank periphery and is about 90 percent purified at this point.

Tertiary Treatment--

The secondary effluent discharged from the final settling tanks flows by gravity to a total of six rapid sand filters. The sand filters filter out the last of the suspended solids and insoluble impurities before discharging the final effluent to the stream.

Post-aeration--

The effluent from sand filters No. 1 and No. 2 flows through a post aeration tank, 8.84m x 3.35m x 2.9m (26ft. x 22ft. x 9.5ft.). Low pressure air enters the tank through diffuser plates.

Chlorination--

Final effluent is chlorinated with an aqueous solution of sodium hypochlorite at the influent end of each sand filter.

Solids Processing and Disposal Facilities--

The primary and waste activated sludge (WAS) generated at the Hanover Park WRP is digested anaerobically and disposed of on a farm adjacent to the WRP. The details of these operations are described below.

Digestion--Primary tank sludge and final tank waste activated sludge (WAS) is pumped into four circular digestion tanks. In these tanks the sludge is heated to between 29° and 35°C (85° and 95°F) and continuously mixed and recirculated for a period of 20 to 25 days. The sludge is heated using methane gas produced from the sludge digestion process. However, natural gas is used for some supplemental heating during the winter.

The digestion tanks are 12.19m (40 ft.) in diameter and have a variable sludge storage depth between 4.42 and 5.94m (14.5 and 19.5 ft.). The sludge depth varies because the covers of the digestion tanks float on top of the liquid sludge.

Sludge Storage Basins--Digested sludge is pumped during winter operations to two diked earth storage basins which have a total storage capacity of approximately 38,230 m^3 (50,000 y^3). The digested sludge is stored in these basins until summer operations, when it is then pumped to the sludge application farm.

Farm Operations--Sludge from the storage basins and sludge from the digesters is pumped during summer to an adjacent farm area owned and operated by the District. The sludge is applied by a grated pipe irrigation system to grow corn, grass, and ornamental trees and shrubs.

Modifications made to the Hanover Park WRP--The layout of the Hanover Park is such that it is very conducive to the study of the effect of recycling digested sludge to the aeration tanks. The four aeration batteries of the WRP are divided into two pairs. One pair (A and B batteries) was operated under the conventional activated sludge mode with separate mesophilic digestion of primary and waste activated sludge (WAS) and no recycling of sludge drawoff to the aeration tanks. This segment of the WRP was designated as the "control section" and was operated continuously without any changes during the entire duration of the study.

The control section of the facility has its own primary and secondary clarifiers, return sludge lines, and two mesophilic digesters (Digester Nos. 1 and 2) operated in series at 35°C with a detention time commensurate with all the sludge produced in this section. Digester No. 1 serves as the primary (1st stage) unit and Digester No. 2 as the secondary (2nd stage) unit.

The "experimental section" of the WRP consists of the aeration batteries C and D. There are two digesters in this section also. Digester No. 3 serves as the primary unit and Digester No. 3 receives the primary sludge and WAS discharged from the aeration batteries. Digester No. 3 is operated as a mesophilic digester at 35°C. The drawoff from this digester was fed to Digester No. 4, which was operated under thermophilic conditions at a temperature of 53°C. There is an adequate heat exchanger capacity and a standby natural gas supply, if needed, to satisfy the heating requirements of thermophilic digestion. After an equilibrium period, a portion of the thermophilic sludge drawoff was recycled into aeration batteries C and D to study the effect of thermophilic sludge recycling on the activated sludge process and sludge production.

The incoming sewage flow was split and fed to the control and experimental sections in proportion to the volume of the aeration batteries in order to achieve similar hydraulic retention times in them. The sewage flows to the control and experimental sections of the WRP were continuously monitored and recorded.

It was necessary to separate the sludge feed lines to the digesters such that the primary and WAS generated from the control section was fed to the Digester Nos. 1 and 2, and the primary and WAS generated from the experimental section to Digester Nos. 3 and 4. These modifications are indicated in Figure 2. The sludge lines prior to the modifications are shown in dotted lines. These were shut off when the study began. The flow pattern of digested sludge is shown in solid lines. The digested sludge drawoff recycling line to the aeration batteries C and D is indicated by a shaded line (i.e. to the aeration tank Nos. 5 to 8 of the experimental section; Figure 2).

ORGANIZATION AND SCHEDULING OF THE VARIOUS EXPERIMENTAL PHASES

The study was divided as indicated earlier into the various phases shown in Table 1 to achieve the objectives of this study. The specific objectives of these various phases are given below.

Phase 1

The main objective of this phase was to segment the Hanover Park WRP into the control and experimental sections and to achieve a steady performance of both the sections. During this phase the start-up and equilibration of Digester No. 4 as a thermophilic digester was accomplished.

Start-up and Equilibration of Digester No. 4--

Digester No. 4 was converted into a thermophilic digester. The temperature of this digester was increased by 1°C every two days from 35°C to 53°C. Previous experience on bench-scale and full-scale digestion experiments at the District (Krup, et al., 1980, and Rimkus, et al., 1982,) has shown that thermophilic operation can be initiated and sustained by subjecting mesophilic digesters to this start-up procedure.

Phase 2

The objective of this phase, was to collect background data on the performance of the control and experimental sections. This phase did not start until operating problems were solved and steady state thermophilic operation could be maintained at all times.

Phase 3

This was the main phase of the entire study, during which various proportions of the thermophilic sludge withdrawn from Digester No. 4 were recycled into the aeration batteries of the experimental section. During phases 3a to 3d approximately 10, 30, 40, and 50 percent of the thermophilic sludge withdrawn from Digester No. 4 was recycled into aeration batteries C and D.

TABLE 1. PHASES OF THE STUDY

Phase	Characteristics
1	Separation of Hanover Park WRP into Control and Experimental Sections. ° Control Section: Conventional activated sludge process with two mesophilic digesters in series. ° No recycling of sludge drawoff into aeration batteries. (Control Section was operated side-by-side with the Experimental Section throughout the study). ° Experimental Section: Conventional activated sludge system with a mesophilic digester operating in series with a thermophilic digester operating at 53°C. ° No recycling of sludge drawoff into aeration tanks.
2	Collection of background data on the performance of Control and Experimental Sections. ° No recycling of thermophilic drawoff into Experimental Section.
3	Initiation of recycling of thermophilic sludge drawoff into Experimental Section aeration batteries. ° 3a. ~10 percent recycling of thermophilic sludge drawoff into aeration batteries of Experimental Section. ° 3b. ~30 percent recycling of thermophilic sludge drawoff into aeration batteries of Experimental Section. ° 3c. ~40 percent recycling of thermophilic sludge drawoff into aeration batteries of Experimental Section. ° 3d. ~50 percent recycling of thermophilic sludge drawoff into aeration batteries of Experimental Section.

In phase 3, when the recycle rate was changed and the operation of a new recycle rate was initiated, the sludge recycling was increased at 5 percent increments with a week's rest in between the increments. When the desired recycling rate was achieved, the experimental section was operated at least for a month before data representative of that rate were collected for that rate.

The main objective of phase 3 was to determine whether the recycling of thermophilic sludge drawoff to the aeration tanks of an activated sludge system would result in less volume and mass of solids to be disposed of in comparison to the solids output from a mesophilic digestion system operated under comparable operating conditions. This phase was conducted in an orderly sequence to minimize the time to achieve equilibrium conditions. However, Phase 2 of this study was conducted for a sufficiently long period to ensure that adequate data were collected to evaluate the base line performance of the control and experimental sections without any recycling of thermophilic sludge into the aeration tanks of the experimental section.

During Phases 2 and 3a through 3d, data were collected to determine the mass balance of solids, effluent quality, nitrogen removals and/or transformations, aeration tank oxygen profiles, heavy metal removals and interactions, if any.

In Phase 2, the dewaterability of the thermophilic and mesophilic sludges was also compared and the polymer dosages determined.

As the study progressed, qualitative data pertaining to odor potential of the thermophilic and mesophilic sludge were recorded.

SAMPLING AND ANALYSIS OF WASTE STREAMS

Sampling points existed at all appropriate locations at the Hanover Park WRP for collecting the following wastewater streams, either as a grab or a composite sample: 1) raw sewage (composite), 2) primary effluent (composite), 3) secondary effluent (composite), 4) digester feed (composite), 5) digester drawoff (composite), and 6) mixed liquor (grab).

Analysis were performed on the different types of samples collected as indicated in Table 2. The frequency of analyses for the various parameters listed in Table 2 was daily, except for the metals and the parameters relating to sludge dewaterability.

Metals were determined twice per week initially during Phase 1. This frequency was curtailed in subsequent phases as it was determined that it was not necessary to do so.

TABLE 2

PROCESS STREAMS AND ASSOCIATED ANALYSES

Process Stream	Total Solids	Total Volatile Solids	Suspended Solids (SS)	VOLATILE SS	BOD (Total)	COD	TKN, NH_4-N	NO_2-N, NO_3-N	Heavy Metals Total and Soluble	Sludge Volume Index	CST, Floc Strength Settling Velocity*	Gas Composition - Gas Volume, % Moisture	Alkalinity, pH	Volatile Acids
Raw Sewage	X	X	X	X	X	X	X	X	X				X	
Primary Effluent	X	X	X	X	X	X	X	X	X				X	
Mixed Liquor			X	X			X	X	X	X			X	
Returned Sludge			X	X			X	X	X	X			X	
Secondary Effluent	X	X	X	X	X	X	X	X	X				X	
Digester Feed	X	X				(T&S)**	X		X		X		X	X
Digester Draw														
-Mesophilic	X	X				(T&S)	X		X		X		X	X
-Thermophilic	X	X				(T&S)	X		X		X		X	X
Digester Gas												X		

*These tests will be complemented by tests such as % solids capture and centrate suspended solids, when pilot-scale studies on centrifuge are conducted.

**T&S means total and soluble, respectively.

After it was determined that equilibrium was attained in a given phase, about eight to ten measurements were made at two day intervals on both soluble and total metals.

The following parameters were determined according to the procedures described in Standard Methods (1985): total solids, total volatile solids, suspended solids, volatile suspended solids, Biochemical oxygen demand (BOD), chemical oxygen demand COD (total and soluble), total Kjeldahl nitrogen (TKN), ammonium-N (NH_4-N), nitrite and nitrate-N (NO_2-NO_3-N), heavy metals (total and soluble), sludge volume index (SVI), alkalinity, and pH. The heavy metals analyzed were zinc, cadmium, copper, chromium, iron, nickel, lead, and mercury.

Samples to be analyzed for soluble metals and COD were filtered through a 0.45 um membrane filters using a pressure filtration apparatus.

Quality Assurance Program Implemented During Study--

The quality assurance guidelines, which are followed within the District's laboratories for the analyses of various chemical parameters are reported by Bogusch, et al. (1985). These procedures were adhered to during the course of this study at the John E. Egan WRP Laboratory where the analyses of the samples collected from the Hanover Park WRP were performed. A copy of this report is included in Appendix A.

An annual audit is conducted by the Quality Assurance Division of the Risk Reduction Engineering Laboratory, Cincinnati, for the National Pollutant Discharge Elimination System (NPDES) parameters. A round robin testing program is conducted among various laboratories using prepared standards through a consulting laboratory. Independent of this program, the USEPA (Region V) also sends audit samples twice a year. The District reports the results of these samples to the USEPA (Region V), which then issues a report to the District stating the accuracy and precision of the analyses. To date the District's laboratories, including the John E. Egan WRP Laboratory where the analyses of various samples collected during the course of this study were performed, have received an overall rating of "Acceptable" for the precision and accuracy of the various analyses performed. Samples of these audit reports for John E. Egan WRP Laboratory are given in Appendix B.

Prior to the initiation of the study, the USEPA's Risk Reduction Engineering Laboratory authorized PEI Associates Inc., Cincinnati, Ohio, to perform an audit of the John E. Egan WRP Laboratory for ascertaining the adequacy of its quality assurance program. A report of this consultant's report indicating the adequacy of such a program is given in Appendix C.

Dissolved Oxygen (DO) Profiles in Aeration Tanks and Oxygen Uptake Patterns of Mixed Liquor--

It was anticipated that the recycling of digested sludge drawoff into the aeration tanks would exert an oxygen demand on the activated sludge system. In order to determine what effect the recycling of thermophilic drawoff would have on the DO concentration of the mixed liquor, DO measurements in the aeration tanks were obtained by a dissolved oxygen probe. Also the oxygen uptake rate of the mixed liquor samples collected at the inlet, middle, and outlet regions of the aeration tanks were obtained. The method used was according to Standard Methods, (1985).

Microbiological Examination--

Samples of mixed liquor were taken once every month from each of the aeration batteries of the control and experimental section for microscopic examination of filaments and other protozoa.

Gas Volume Measurement--

The volume of gas produced from the digesters was directly read from the gas meters installed at the Hanover Park WRP. Grab samples of digester gas were collected twice during each phase in glass bulbs. Gas chromatographic techniques were used to determine the percent methane and carbon dioxide in the digester gas.

Measures Taken to Improve Gas Volume Measurement

The Hanover Park WRP digesters leak gas to the atmosphere continuously through safety relief valves located on the digester covers and from the annular space between the digester cover and the wall. The leaked gas was not included in the gas volume measurements. It is impractical to control the gas losses from the annular space. However, numerous efforts were made to correct the leakage of gas from the safety relief valves. These efforts included the following:

1) Installation of new cover vents,
2) Installation of new underground piping to the waste gas burners,
3) Installation of new gas meters,
4) Refurbishing and/or the installation of new flame cells,

5) Back-flushing the gas piping with 90 psi effluent water,
6) Refurnishing condensate traps,
7) Refurbishing the heat-exchanger burners,
8) Installation of water removal traps at various low points on the gas piping system,
9) Refurbishing some of the check valves on the gas piping system,
10) Dismantling and cleaning the inside of some piping or replacing some that could not be used,
11) Installation of pressure regulators for the heat exchangers,
12) Refurbishing existing waste gas pressure regulators, and
13) Replacement of electrical transmitters associated with the gas measuring system.

These efforts reduced the gas losses to a low level. However, uncertainty as to the magnitude of these losses prevented use of measured gas production for evaluating digester performance.

Maintenance of Digesters During Winter Weather

In order to minimize the tilting of the digester covers due to freezing of the covers to the digester walls and freezing of the gas relief flame arrestors, certain measures were implemented. Digester Nos. 3 and 4 were operated with cover heights 0.3m (1 ft.) below normal operating levels to prevent damage to internal piping. In order to move the digester covers more frequently, the transfer of sludge drawoff from Digesters 1 and 3 to Digesters 2 and 4, respectively, was made in 0.15m (0.5 ft.) increments instead of 0.3m (1.0 ft.) increments as practiced during fair weather operation. Also, bales of straw were installed on the periphery of all digester covers to prevent the freezing of the covers to the digester walls. Heat tapes were installed on all relief valve flame arrestors to prevent freezing, which could cause cover tilts due to excessive pressures.

Calibration of Sewage and Air Flow Meters

As the reliability of flow measurements was crucial to the validity of the final outcome of this study, a program of routine calibration of sewage flow meters was instituted. There were twenty-five sewage flow meters that are relevant to the study at the Hanover Park WRP. Every three months these were calibrated by professional instrument mechanics of the District. There are also twenty-eight air flow meters. These were also calibrated every three months.

Digester Feed (Raw Sludge) Flow Measurements

It was crucial to have accurate measurements of the sludge fed to the control and experimental digesters for determining the mass balances in the study. Hence, considerable effort was made to obtain accurate readings of the flows of the sludge fed to the digesters.

Three procedures were used for measuring the volume of sludge fed to the primary digesters of the control and experimental sections (Digester Nos. 1 and 3, respectively) and the flow of drawoff from the secondary digesters (Digester Nos. 2 and 4, respectively). These were: 1) measuring the changes of sludge level in the holding tanks from which the sludge is pumped into the digesters, 2) counting the plunger strokes registered on the stroke counters installed on the sludge feed pumps, and 3) measuring the changes in the heights of the floating covers on the digesters. The third procedure was ultimately used since it produced the most reliable data.

Calibration of the Thermophilic Sludge Recycling Pump

Various quantities of thermophilic sludge drawoff were recycled into the aeration batteries of the experimental section of the Hanover Park WRP during Phase 3. These flows were calibrated by using a stop watch and a 208-liter (55-gallon) drum. The dial on the recycling pump was set during each part of Phase 3 to yield the desired flow rates. During Phase 3a, the discharge of the recycling pump was initially checked every week for about four weeks. As there was little change in the discharge rate of the recycling pump, flow calibration checks were then made twice or thrice in a given part of Phase 3. This was found to be adequate for maintaining the desired recycling rates through out Phase 3.

Centrifuge Dewatering of Mesophilic and Thermophilic Sludge Drawoff

Laboratory studies were conducted utilizing a capillary suction time (CST) apparatus (Triton Electronics Ltd., Dunmow, Essex, England) to obtain information on the floc strength of the mesophilic and thermophilic drawoffs from Digesters 2 and 4 and to determine the polymer dosage required to achieve the lowest possible CST with these sludges. These dewatering experiments were conducted during Phase 2.

The CST determinations were made according to the procedures described by Baskerville and Gale (1968). The floc strength was determined according to the procedure described by Vesilind (1979).

Pilot-scale studies were also conducted using a Robatel centrifuge to determine the dewaterability performance of the sludges using Allied Colloids 763 polymer. The optimal dose of this polymer was determined to obtain the highest capture and cake solids concentration.

MASS BALANCE OF VOLATILE SOLIDS AROUND VARIOUS UNIT PROCESSES

Five mass balances of the volatile solids around different unit processes were made in order to understand the nature of their flow around the various unit operations of the control and experimental sections. In addition, computations of the flow volume of the thermophilic sludge recycled to the experimental section aeration batteries were made to determine whether the calculated volume actually returned to the digesters after passing through the aeration batteries. These are as follows:

a. Volatile Solids Mass Balances:
   1. Around the aeration batteries,
   2. Around the secondary settling tanks,
   3. Around the aeration plus secondary settling tanks,
   4. Around the primary settling tanks,
   5. Around the primary plus secondary digesters.

b. Volume balance on Digester 4 drawoff.

Mass Balance Around Aeration Batteries

The fundamental equation for a mass balance for a conserved component is:

Input - output = accumulation.

The terms can be expressed as rates, or as cumulative amounts over a specific time interval. The latter approach has been used in the equations that follow. When the balances are for materials that are not conserved, appropriate terms accounting for the gain or loss of material are introduced into the balances.

A mass balance of the volatile solids entering the aeration batteries of the control and experimental sections was computed taking into consideration the volatile solids inputs to the aeration batteries. The input streams to the aeration batteries of the control section are the primary effluent and the returned sludge, whereas the aeration batteries of the experimental section receive digested sludge drawoff in addition to the primary effluent and returned sludge as their inputs. The output of volatile solids from the aeration batteries is in the mixed liquor discharged from them. The mass of inputs should equal the mass of outputs + or - the gain or loss of mass of material from the reactor due to biological or chemical phenomena. The input and output streams are shown in Figure 3.

The following equation relates the mass inputs and outputs of volatile suspended solids for the aeration batteries of the control section.

$$Q_{peC} \cdot X_{peC} + Q_{rsC} \cdot X_{rsC} + G_{aC} = Q_{mlC} \cdot X_{mlC} + A_{aC} \quad (1)$$

Similarly, the mass balance of volatile suspended solids for the experimental section aeration batteries can be represented as follows:

$$\begin{aligned} &Q_{peE} \cdot X_{peE} + Q_{rsE} \cdot X_{rsE} + Q_{ddE} \cdot X_{ddE} + G_{aE} \\ &= Q_{mlE} \cdot X_{mlE} + A_{aE} \qquad (2) \end{aligned}$$

The nomenclature for Equations 1 and 2 are given below:

Q_{peC} = primary effluent flow volume into A&B batteries, m^3
X_{peC} = primary effluent VS concentration, mg/L
Q_{rsC} = return sludge flow in, m^3
X_{rsC} = return sludge VS concentration, mg/L
Q_{mlC} = mixed liquor flow out, m^3
X_{mlC} = mixed liquor VS concentration, mg/L
G_{aC} = net gain in VSS,g
A_{aC} = Accumulation of VSS in the aeration tanks, g
Q_{peE} = primary effluent flow into C&D batteries, m^3
X_{peE} = primary effluent VS concentration, mg/L
Q_{rsE} = return sludge flow in, m^3
X_{rsE} = return sludge VSS concentration, mg/L
Q_{ddE} = digester draw flow in, m^3
X_{ddE} = digester draw VS concentration, mg/L
Q_{mlE} = mixed liquor flow out, m^3
X_{mlE} = mixed liquor VSS concentration, mg/L
G_{aE} = net gain in VSS,g
A_{aE} = accumulation of VSS in the aeration tanks,g
(Subscripts: pe = primary effluent
rs = return sludge
ml = mixed liquor
dd = digester drawoff
a = aeration tanks)

The balance that is made is a volatile suspended solids balance. In the aerator, some volatile suspended solids are dissolved by bacterial action. Some of the dissolved solids are converted to bacterial cells (which are suspended solids)

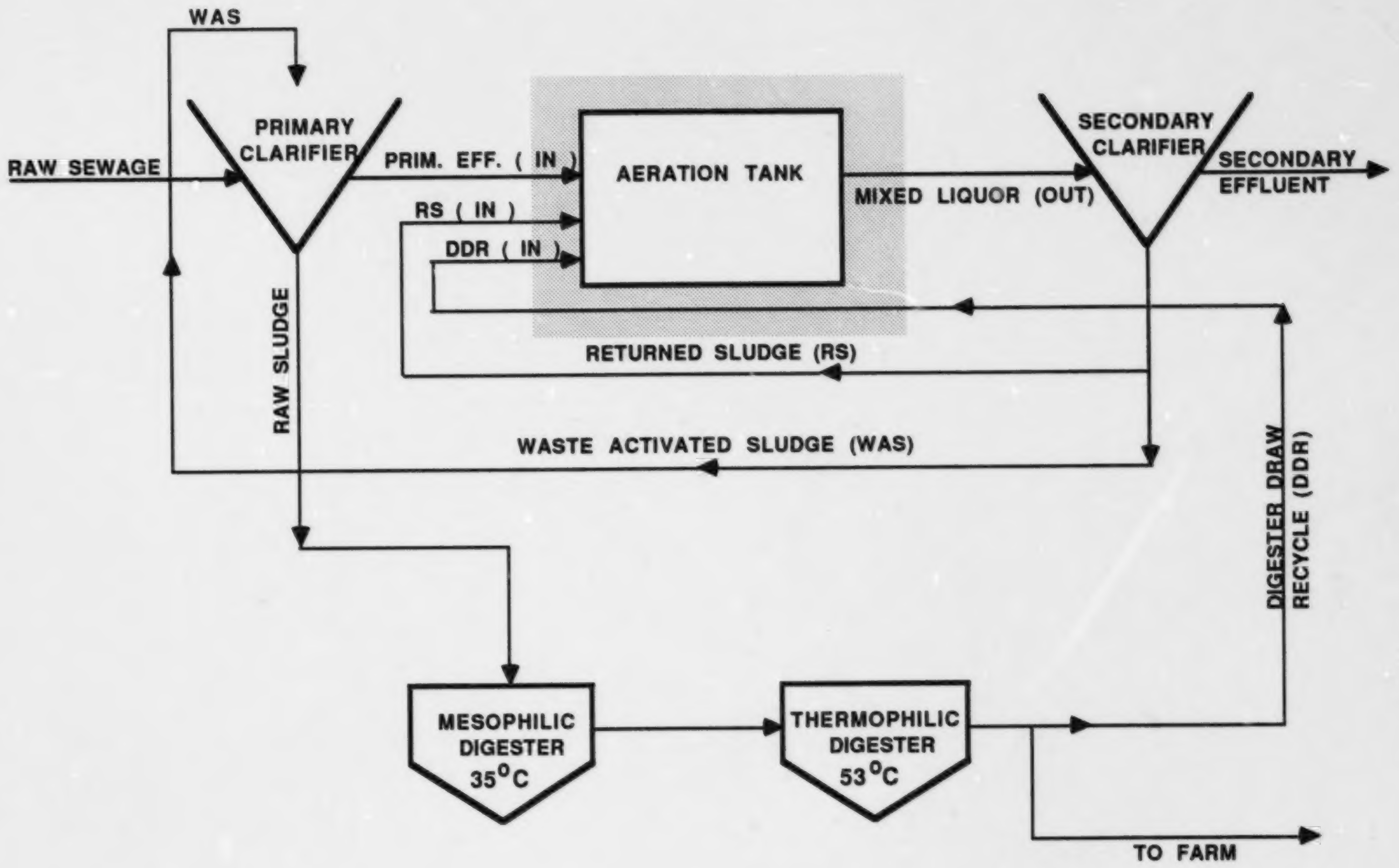

WAS
PRIMARY CLARIFIER
RAW SEWAGE
PRIM. EFF. (IN)
RS (IN)
DDR (IN)
AERATION TANK
MIXED LIQUOR (OUT)
SECONDARY CLARIFIER
SECONDARY EFFLUENT
RAW SLUDGE
RETURNED SLUDGE (RS)
WASTE ACTIVATED SLUDGE (WAS)
DIGESTER DRAW RECYCLE (DDR)
MESOPHILIC DIGESTER 35°C
THERMOPHILIC DIGESTER 53°C
TO FARM

Figure 3 : MASS BALANCE OF VOLATILE SOLIDS AROUND AERATION TANKS

and there are discrepancies caused by inaccuracies in measurement. The term G_a is the summation of these three effects. Normally in an activated sludge aerator there is a net production of volatile suspended solids; hence, the summation term is written as a gain (Ga), and it is shown on the input side of the equation. (The term G_a could be a gain or a loss. If the primary effluent were a soluble waste with no suspended solids , activated sludge mass would increase, and clearly there would be a net gain in mass. On the other hand, if the primary effluent contained only biodegradable solid particles and no solubles, G_a could be negative).

The A_a term is the accumulation of volatile suspended solids in the aerator. It is the product of the active volume of the aerator and the difference in VSS concentrations at the end and the beginning of the experimental period.

As noted above, the balance to be drawn is a volatile suspended solids balance. In Equation 2 for the experimental section, the solids measurement in the digester return (X_{dde}) is a volatile solids measurement, not volatile suspended solids. However, the solids content measured in digested sludge samples of our experiments, VS and VSS concentrations are nearly identical. Consequently, the error introduced by using VS instead of VSS for the digested sludge is minimal.

Mass Balance Around Secondary Clarifiers

A schematic of the materials flow into the secondary settling tanks is given in Figure 4. The input of volatile solids mass into these settling tanks is from the mixed liquor discharged from the aeration batteries. The total output of the volatile solids mass from these tanks arise from three streams, viz. secondary effluent, waste activated sludge, and returned sludge.

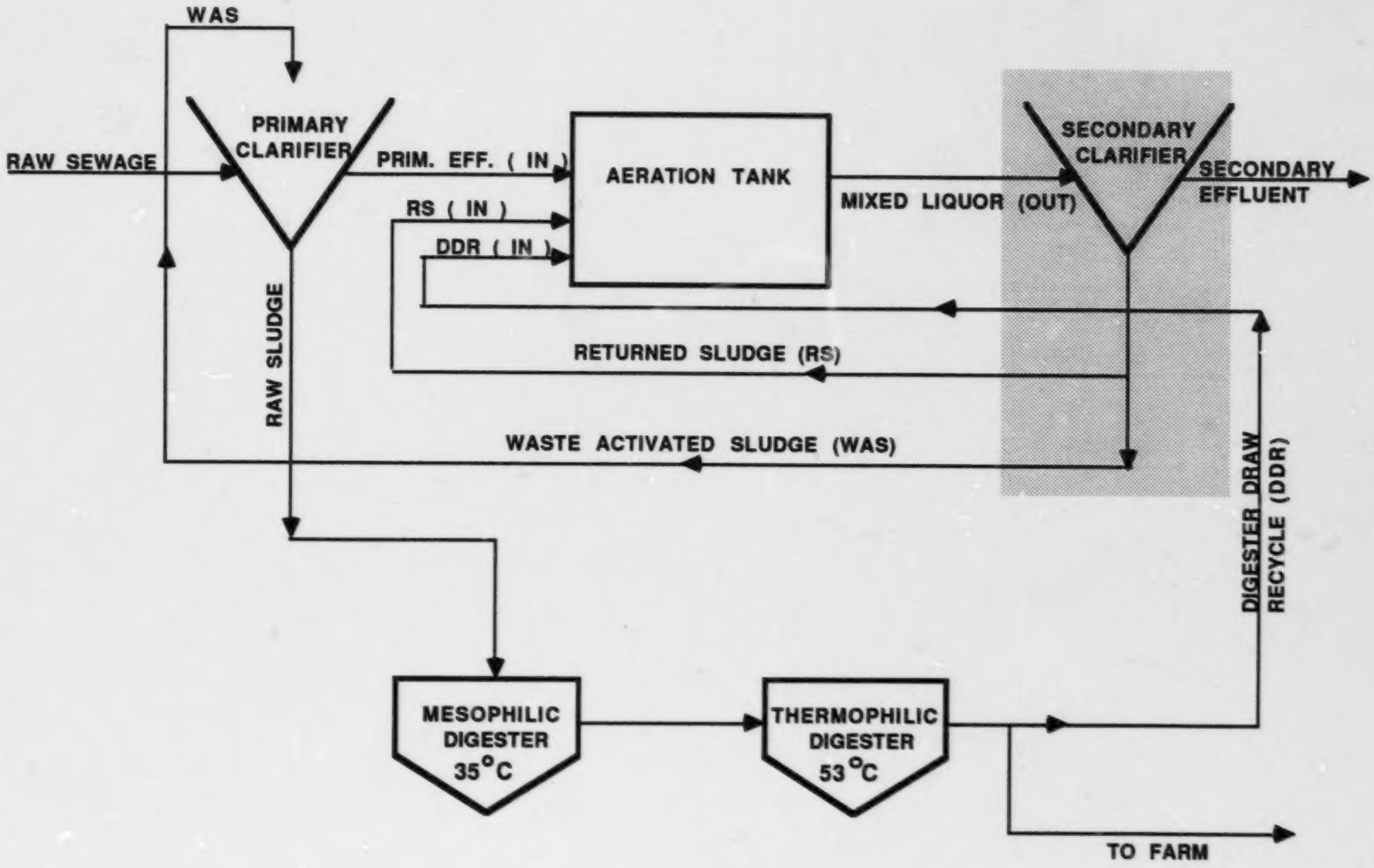
The following equations represent the mass balance of volatile solids around the secondary clarifiers associated with the control and experimental sections aeration batteries.

$$Q_{mlC} \cdot X_{mlC} = Q_{seC} \cdot X_{seC} + Q_{wasC} \cdot X_{wasC} + Q_{rsC} \cdot X_{rsC} + D_{scC} + A_{scC} \text{ and;} \tag{3}$$

$$Q_{mlE} \cdot X_{mlE} = Q_{seE} \cdot X_{seE} + Q_{wasE} \cdot X_{wasE} + Q_{rsE} \cdot X_{rsE} + D_{scE} + A_{scE} \tag{4}$$

where:

Q_{mlC} = flow of mixed liquor from A&B batteries, m^3
X_{mlC} = VSS concentration of mixed liquor of A&B batteries, mg/L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RS (IN)
DDR (IN)
AERATION TANK
MIXED LIQUOR (OUT)
SECONDARY CLARIFIER
SECONDARY EFFLUENT
RAW SLUDGE
RETURNED SLUDGE (RS)
WASTE ACTIVATED SLUDGE (WAS)
DIGESTER DRAW RECYCLE (DDR)
MESOPHILIC DIGESTER 35°C
THERMOPHILIC DIGESTER 53°C
TO FARM

Figure 4 : MASS BALANCE OF VOLATILE SOLIDS AROUND SECONDARY CLARIFIERS

Q_{seC} = flow of effluent from A&B batteries secondary settling tanks, m^3

X_{seC} = VSS concentration of secondary effluent of A&B batteries, mg/L

Q_{wasC} = flow of WAS from A&B batteries settling tanks, m^3

X_{wasC} = VSS concentration of WAS from A&B batteries, mg/L

Q_{rsC} = flow of returned sludge from A&B batteries, m^3

X_{rsC} = VSS concentration of RS from A&B batteries, (same as WAS), mg/L

D_{scC} = Difference, g

A_{scC} = accumulation, g

Subscript: sc = secondary clarifier

Equation 4 for the experimental section is identical in form to Equation 3 for the control section except subscript E replaces subscript C.

The accumulation term (A_{sc}) in Equation 3 and 4 is calculated in exactly the same manner as for Equations 1 and 2. The term D_{sc} is introduced to account for inaccuracies in experimental measurements. Since there is no substantial biological activity in a clarifier, input should exactly equal the sum of output and accumulation. This is rarely the case, so a term, difference (D_{sc}) is introduced. If D_{sc} is an excessively large percentage of total input, large errors are indicated in the experimental measurements which may cast doubt on the validity of results.

Mass Balance of Volatile Solids Around the Aeration plus the Secondary Settling Tanks

This mass balance represents the flow of volatile solids entering the aeration tanks of the control and experimental sections and those leaving the secondary clarifiers. A schematic of this is given in Figure 5.

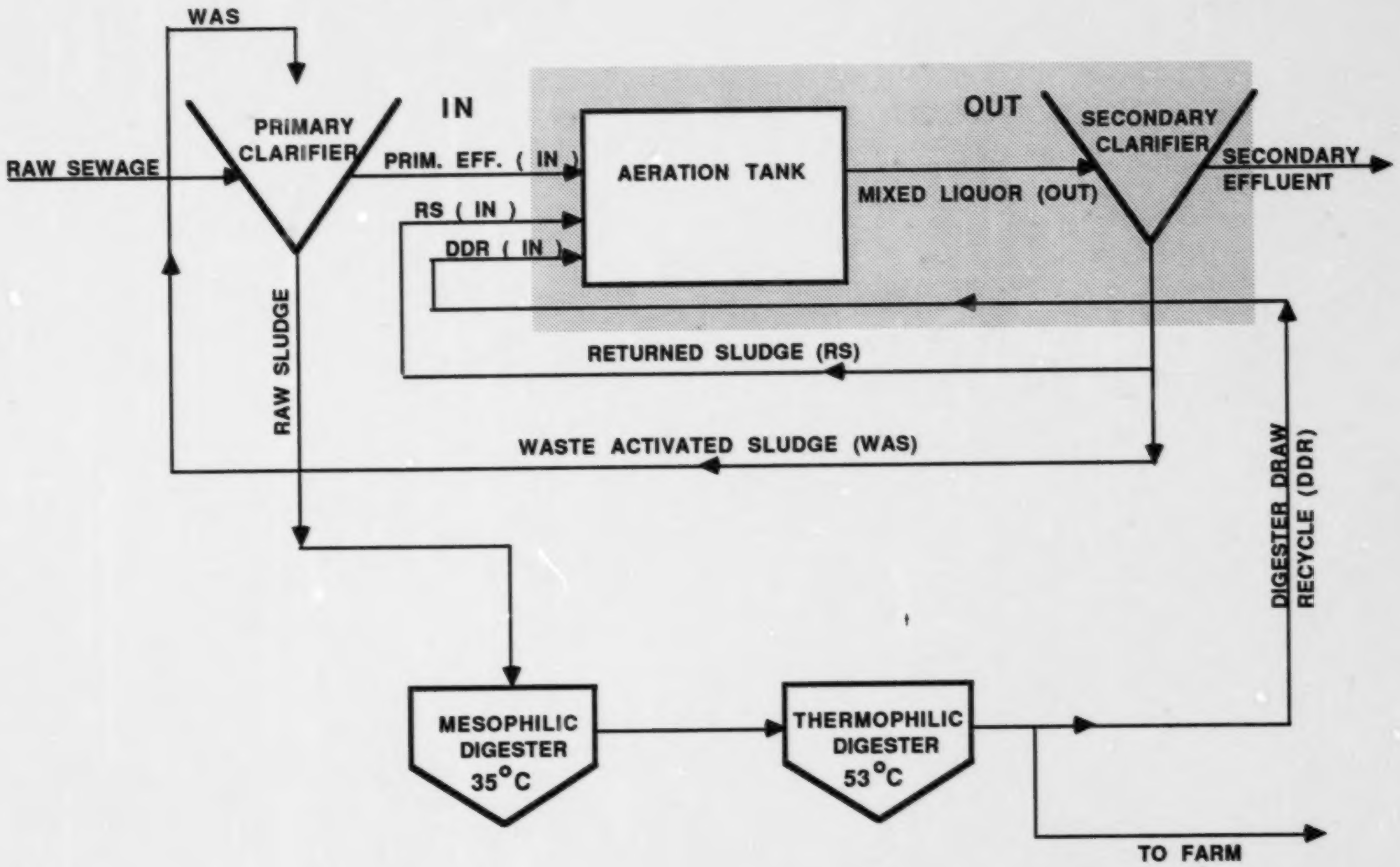
This mass balance is nothing more than the sum of the mass balances around the aerator and the mass balance around the secondary clarifier. The summations of the two equations Equations 1 and 3 for the control section, Equations 2 and 4 for the experimental section) are given below:

Control Section

$$Q_{peC} \cdot X_{peC} + (G_{aC} - D_{scC}) = Q_{seC} \cdot X_{seC} + Q_{wasC} \cdot x_{wasC} + A_{aC} + A_{scC} \qquad (5)$$

Experimental Section

$$Q_{peE} \cdot X_{peE} + Q_{ddE} \cdot X_{ddE} + (G_{aE} - D_{scE}) = Q_{seE} \cdot X_{seE} + Q_{wasE} \cdot X_{wasE} + A_{aE} + A_{scE} \qquad (6)$$


WAS
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OUT
PRIMARY CLARIFIER
RAW SEWAGE
PRIM. EFF. (IN)
RS (IN)
DDR (IN)
AERATION TANK
MIXED LIQUOR (OUT)
SECONDARY CLARIFIER
SECONDARY EFFLUENT
RAW SLUDGE
RETURNED SLUDGE (RS)
WASTE ACTIVATED SLUDGE (WAS)
DIGESTER DRAW RECYCLE (DDR)
MESOPHILIC DIGESTER 35°C
THERMOPHILIC DIGESTER 53°C
TO FARM

Figure 5 : MASS BALANCE OF VOLATILE SOLIDS AROUND AERATION TANKS AND SECONDARY CLARIFIERS

Application of these equations to the time periods of the various phases in the investigation showed that the accumulation terms were insignificant. This is due to the fact that the residence time and solids contents are low in the aerators and clarifiers; so total holdup of mass in these vessels is low relative to total inputs and outputs.

In the Results Section, the actual MLVSS entering the control and experimental sections aeration batteries through the various streams and the MLVSS leaving the secondary clarifiers via the various streams as shown in Figure 5 along with the net and percent differences between the input and output MLVSS mass are presented.

Mass Balance of Volatile Suspended Solids around Primary Clarifers

A schematic of the volatile suspended solids flow into the primary clarifiers of the control and experimental sections along with the flow of volatile solids into their corresponding digesters is given in Figure 6.

The volatile suspended solids balance around the primary clarifier is given below. The balance is the same for control and experimental section so only one equation is shown:

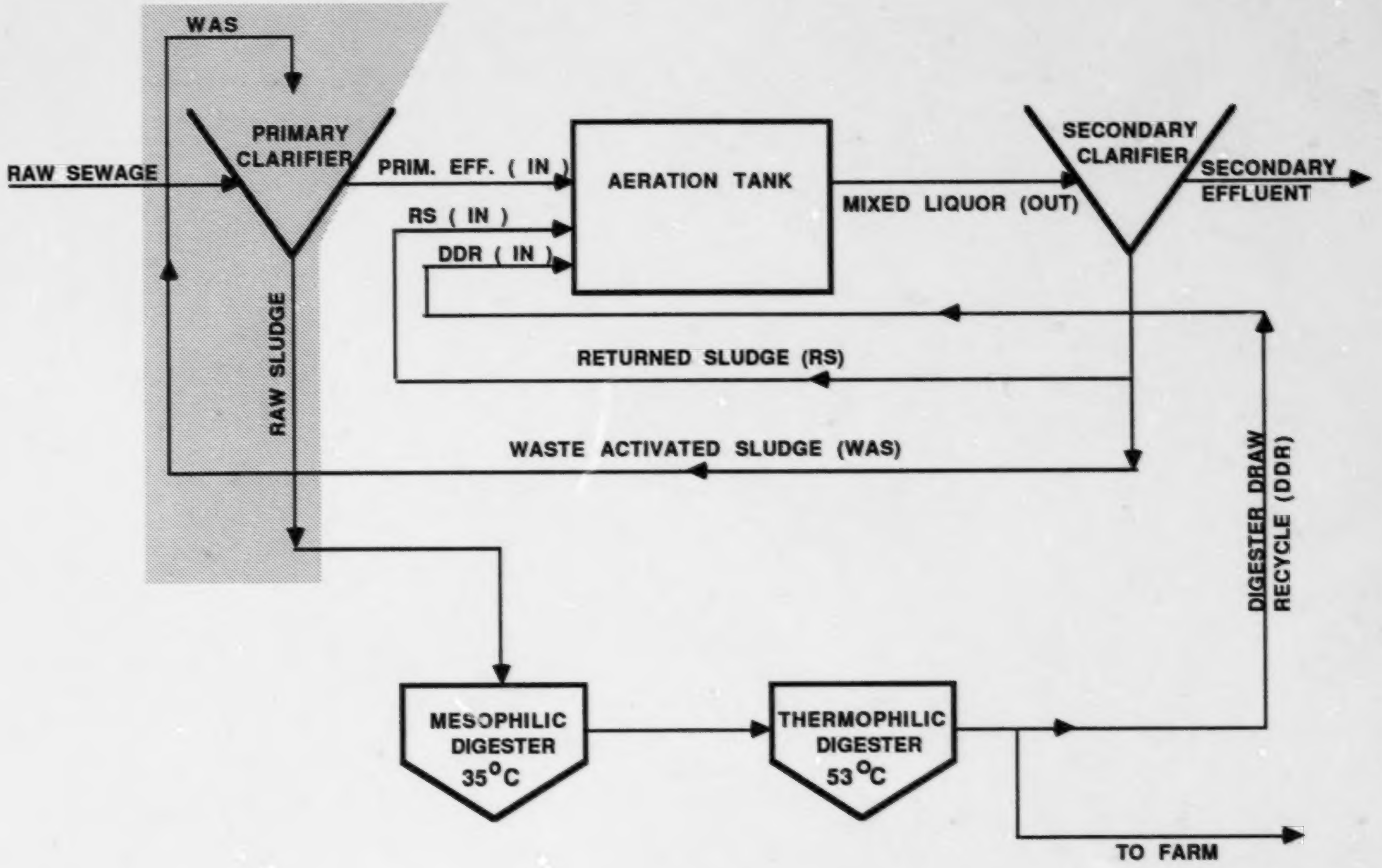
$$Q_{rs} \cdot X_{rs} + Q_{was} \cdot X_{was} = Q_{pe} \cdot X_{pe} + Q_{rsl} \cdot X_{rsl} + D_{pc} + A_{pc} \qquad (7)$$

where
Q = Total flow volume
X = VSS concentration
D = difference
A = accumulation

Subscripts
rs = raw sewage
was = waste activated sludge
rsl = raw sludge
pe = primary effluent
pc = primary clarifier

The terms D and A have been explained in previous sections. Note that the X measured for the raw sludge was VS, not VSS. The difference between the two for relatively concentrated sludges is generally trivial.

In performing a mass balance around a primary clarifier, it is important to note the location of the raw sewage sample. In the Hanover Park WRP, raw sewage is sampled before the addition of waste activated sludge to the primary clarifier.


WAS
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RAW SEWAGE
PRIM. EFF. (IN)
AERATION TANK
MIXED LIQUOR (OUT)
SECONDARY CLARIFIER
SECONDARY EFFLUENT
RS (IN)
DDR (IN)
RAW SLUDGE
RETURNED SLUDGE (RS)
WASTE ACTIVATED SLUDGE (WAS)
DIGESTER DRAW RECYCLE (DDR)
MESOPHILIC DIGESTER 35°C
THERMOPHILIC DIGESTER 53°C
TO FARM

Figure 6 : MASS BALANCE OF VOLATILE SOLIDS AROUND PRIMARY CLARIFIERS

If it is assumed that D_{pc} is small, it is possible to use Equation 7 to calculate $Q_{rsl} \cdot X_{rsl}$ the VSS input to the digesters. This term was also directly measured - flow rate and VS content of the raw sludge were determined. The direct measurement was chosen as the best estimate of mass of volatile solids charged to the digesters.

Mass Balance of Volatile Solids Around the Control and Experimental Digesters

A schematic indicating the flow of volatile solids into and out of the digesters is given in Figure 7. The feed to the primary digesters (Digester Nos. 1 and 3) of the control and experimental sections consisted of the underflow of the primary clarifiers associated with them.

The volatile solids of the feed to Digester No. 1 were calculated by adding the mass of volatile solids contained in the primary sludge withdrawn from the primary clarifiers of Battery A and the mass of volatile solids contained in the primary sludge withdrawn from the clarifiers of Battery B. This computation has to be done this way since the primary sludge from the primary clarifiers associated with these batteries is not discharged into a common tank as in the case of primary clarifiers of Batteries C and D. The mass of volatile solids fed to Digester No. 3 was obtained by multiplying the flow of the primary sludge from the primary clarifiers of Batteries C and D and its solids concentration. The flow volumes of the sludge from the primary clarifiers of Batteries A, B, C, and D were read from the strip chart recorder located on the process control panel at the Hanover Park WRP. Digester draw samples were obtained from the primary as well as the secondary digesters of these sections (Digester Nos. 2 and 4, respectively) and the volatile solids determined.

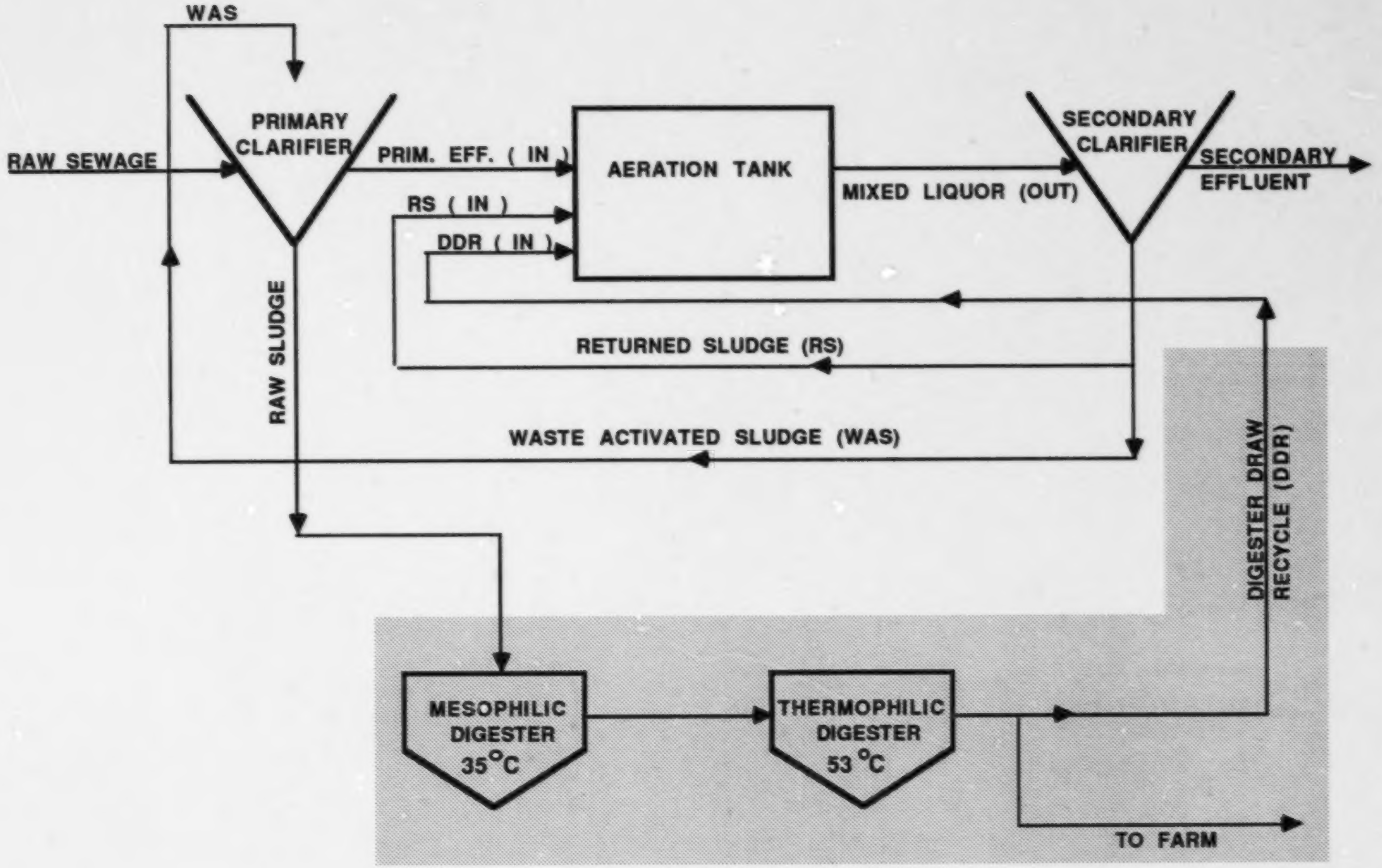
The mass balance of the volatile solids in the digester portion of the control and experimental sections of the Hanover Park WRP can be represented by the following equations.

Control Section:

$$Q_{df(1)} \cdot X_{df(1)} = Q_{dd(2)} \cdot X_{dd(2)} + VS_{(L1-2)} + A_{d(1-2)} \quad (8)$$

where,

$Q_{df(1)}$ = Digester feed flow to Digester No. 1, m^3
$X_{df(1)}$ = VS concentration of Digester No. 1 feed, kg/m^3,
$Q_{dd(2)}$ = Digester No. 2 drawoff flow, m^3,
$X_{dd(2)}$ = VS concentration of Digester no. 2 draw, kg/m^3,


WAS
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RS (IN)
DDR (IN)
AERATION TANK
MIXED LIQUOR (OUT)
SECONDARY CLARIFIER
SECONDARY EFFLUENT
RAW SLUDGE
RETURNED SLUDGE (RS)
WASTE ACTIVATED SLUDGE (WAS)
DIGESTER DRAW RECYCLE (DDR)
MESOPHILIC DIGESTER 35°C
THERMOPHILIC DIGESTER 53 °C
TO FARM

Figure 7 : MASS BALANCE OF VOLATILE SOLIDS AROUND DIGESTERS

$VS_{(L1-2)}$ = Volatile Solids lost in Digesters 1 and 2, kg,
$A_{d(1-2)}$ = accumulation of volatile solids in Digesters 1 and 2,

Experimental Section:

$$Q_{df(3)} \cdot X_{df(3)} = Q_{dd(4)} \cdot X_{dd(4)} + VS_{(L3-4)} + A_{d(3-4)} \quad (9)$$

where,

$Q_{df(3)}$ = Digester feed flow to Digester No. 3, m^3,
$X_{df(3)}$ = VS concentration of Digester No. 3 feed, kg/m^3,
$Q_{dd(4)}$ = Digester No. 4 drawoff flow, m^3,
$X_{dd(4)}$ = VS concentration of Digester No. 4 draw, kg/m^3,
$VS_{(L3-4)}$ = Volatile Solids lost in Digesters 3 and 4,
$A_{d(3-4)}$ = accumulation of volatile solids in Digesters 3 and 4, kg
Subscript d = digester

Note that the balances around the digesters are VS balances, not VSS balances. As noted earlier, the difference between VSS and VS is generally trivial for sludges above about 1 percent solids.

The VS term includes the loss of VS by conversion to gas and water, the synthesis of biomass, and inaccuracies in measurement. Ordinarily the loss by conversion to gas and water is the dominant term, so it is shown on the output side of the equation as a loss term.

The length of the phases were sufficiently long that the accumulation terms were small relative to total input. However, they generally were significant enough to include in the balances around the digesters.

SECTION 4

RESULTS

PERFORMANCE OF THE CONTROL AND EXPERIMENTAL SECTIONS (BASE LINE)

Before the recycling of thermophilic sludge was initiated into the aeration batteries of the experimental section of the Hanover Park WRP, data were collected on the performance of the control and experimental sections (Phase 2). These performance data were used as the base line or reference data for enabling the comparison of the performance of the experimental section (batteries C and D and their associated clarifiers and digesters) with that of the control section (batteries A and B and their associated clarifiers and digesters), when no thermophilic sludge was recycled into the aeration batteries of the experimental section. In addition, the Phase 2 data were also used to compare the performance of both the control and experimental sections during Phase 3 of the study. Such data included the operational parameters, effluent quality, sludge production, digester performance, and quantities of sludge ultimately disposed on the farm from the control and experimental sections of the Hanover Park WRP.

In the following sections, all the data collected during the study were grouped according to the various phases (Table 1) of the study. Thermophilic sludge drawoff withdrawn from Digester No. 4 was recycled into the aeration batteries of the experimental section during the sub-phase of Phase 3. during the sub-phases of Phase 3. About 13, 30, 40, and 50 percent of the thermophilic sludge withdrawn from digester No. 4 was recirculated to the experimental section aeration batteries in the sub-phases 3a, 3b, 3c, and 3d respectively. No thermophilic sludge was recycled into the experimental section aeration batteries during Phase 2.

Monthly averages of all the plant data collected during Phases 2 and 3 and the averages for these two phases are given in Appendix Tables D-1 through D-5 and E-1.

Operational Characteristics and Parameters

Influent Flow During Various Phases--

The influent flows processed for all the phases of the study by aeration batteries A, B,C and D and by the control (A and B batteries) and experimental (C and D batteries) sections are given in Figure 8 and 8a. From Figure 8 it can be seen that the flow treated in Battery A was lower than in

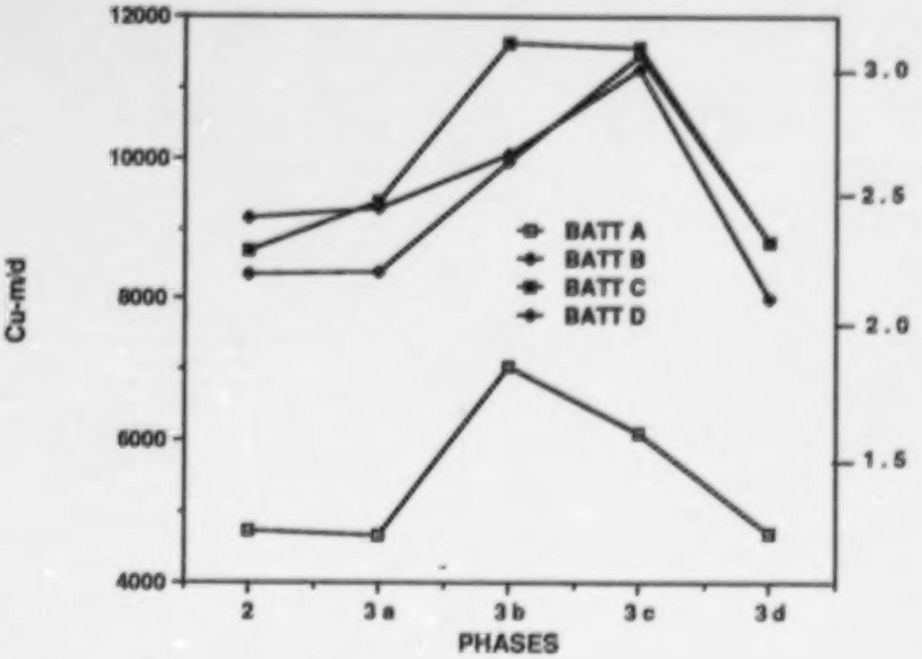


FIGURE 8 : AVERAGE INFLUENT FLOW INTO INDIVIDUAL AERATION BATTERIES

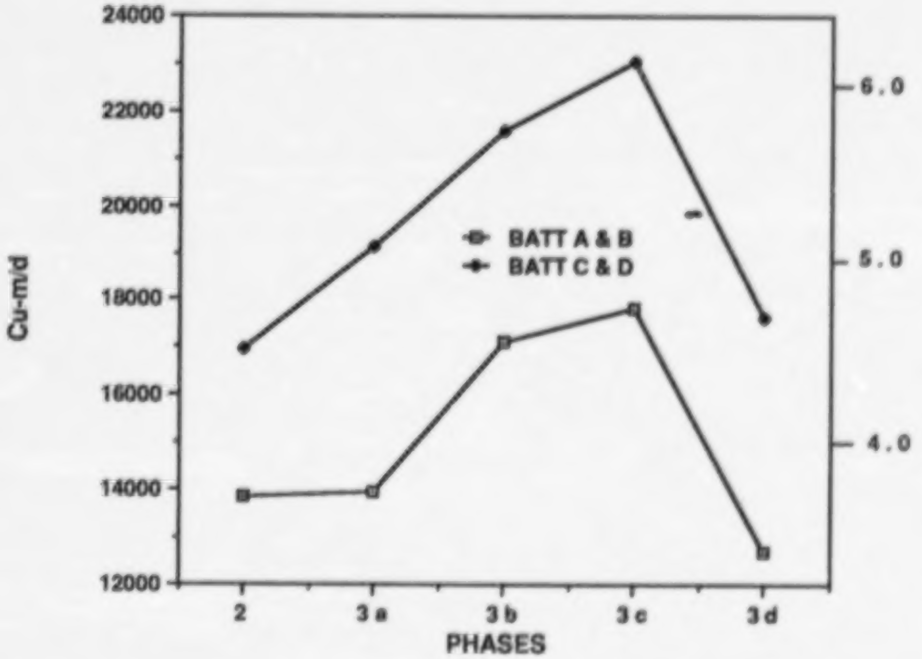


FIGURE 8a : AVERAGE INFLUENT FLOW OF CONTROL AND EXPERIMENTAL SECTIONS

other batteries. This is due to the fact that Battery A is smaller than the other batteries (Batteries B, C, and D, which are equal in size). However, the hydraulic retention time was approximately the same in all the batteries. The experimental section, which is 25 percent larger in capacity than the control section processed 22 to 39 percent more flow than the control section during the various phases (Figure 8a).

In Phases 3C and 3D, considerably larger volumes of flows were processed than in the other phases due to heavy precipitation during these periods.

Hydraulic Retention Time in Batteries--

The operational strategy employed at the Hanover Park WRP was to maintain an equal hydraulic retention time (HRT) and an equal mixed liquor suspended solids concentration (MLSS) in all the aeration batteries on any given day. The HRT would vary among days, depending on the flow received at the plant. Thus, the average HRT computed for any phase is related to the average flow volume processed per day during that phase.

The average HRTs maintained in the individual aeration batteries and collectively for the control and experimental sections of the Hanover Park WRP for the various phases are given in Figures 9 and 10. Overall, the HRTs for the various batteries in any given phase were very close, although there were some variations among the phases. The overall range for the average HRTs maintained in the individual batteries was 8.7 to 12.8 hrs (Figure 9). The average HRTs for the control and experimental sections were very similar during Phases 2, 3a, 3b, and 3c (Figure 10). However, the HRT of the control section was roughly one and one half hours more than the experimental section during Phase 3d. This was due to a disproportionate distribution of the influent to the two sections with respect to their sized during this phase, which could not be controlled.

The profile of the average solids retention time (SRT) that occurred during the various equilibrium phases is given in Figure 11.

The batteries were run to maintain a constant HRT. A constant MLSS concentration was monitored and controlled by adjusting the amount of return sludge wasted. Under these conditions, SRT depends in a inverse fashion on the net rate of increase in suspended solids. The net increase in solids depends on how much of the incoming solids is consumed and solubilized, how much bacterial mass is generated, how much suspended solids is lost into the secondary effluent, and how much of activated sludge solids wasted.

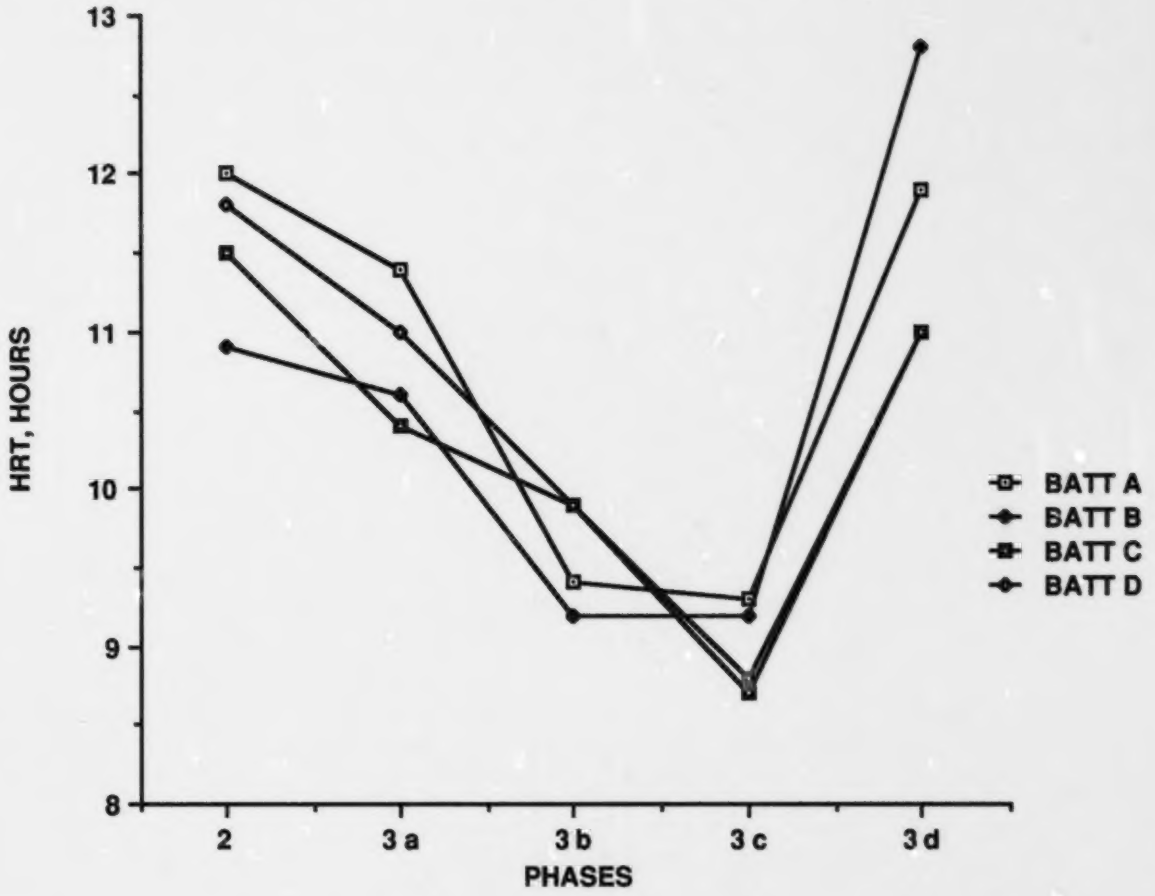


FIGURE 9 : AVERAGE HYDRAULIC RETENTION TIME OF AERATION BATTERIES

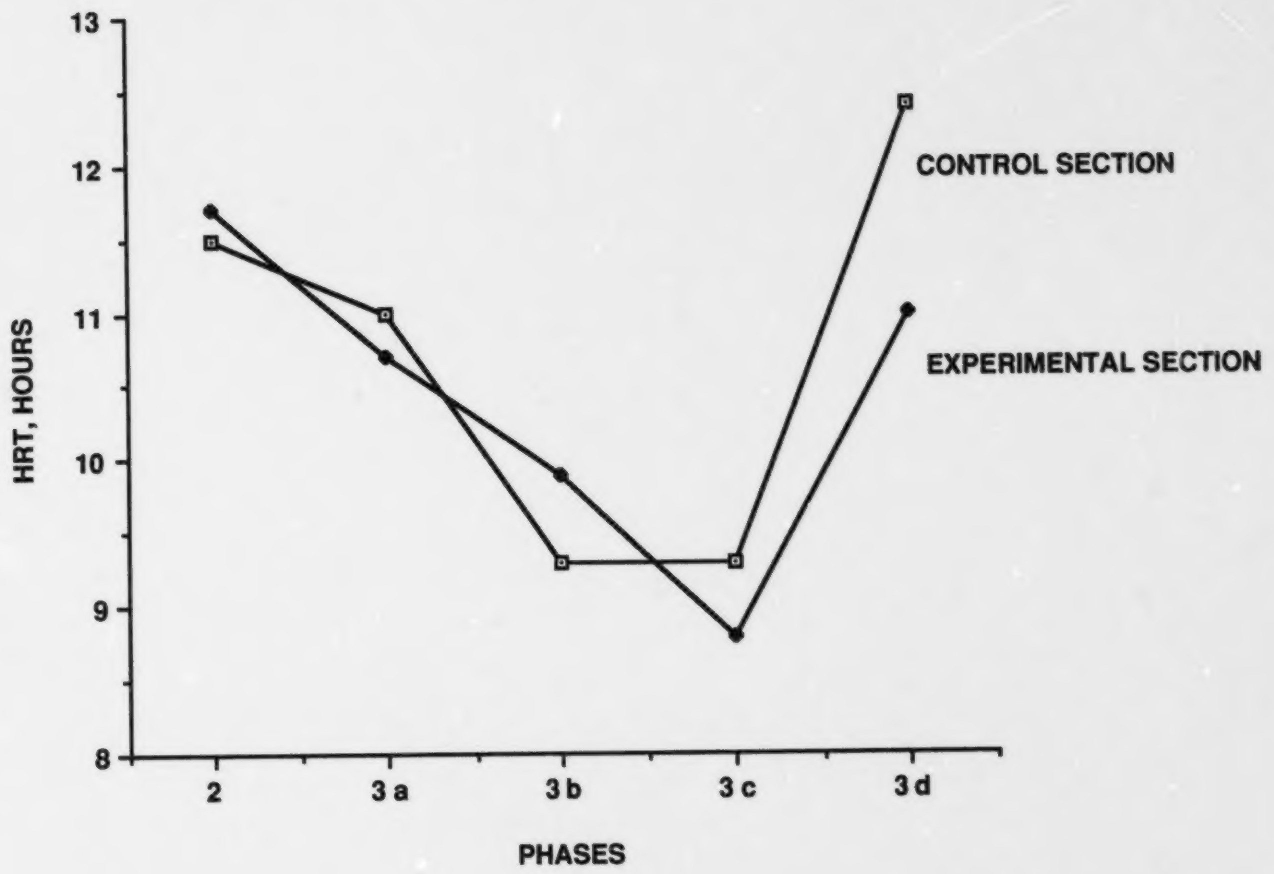


FIGURE 10 : AVERAGE HYDRAULIC RETENTION TIME OF CONTROL AND EXPERIMENTAL SECTIONS AERATION BATTERIES

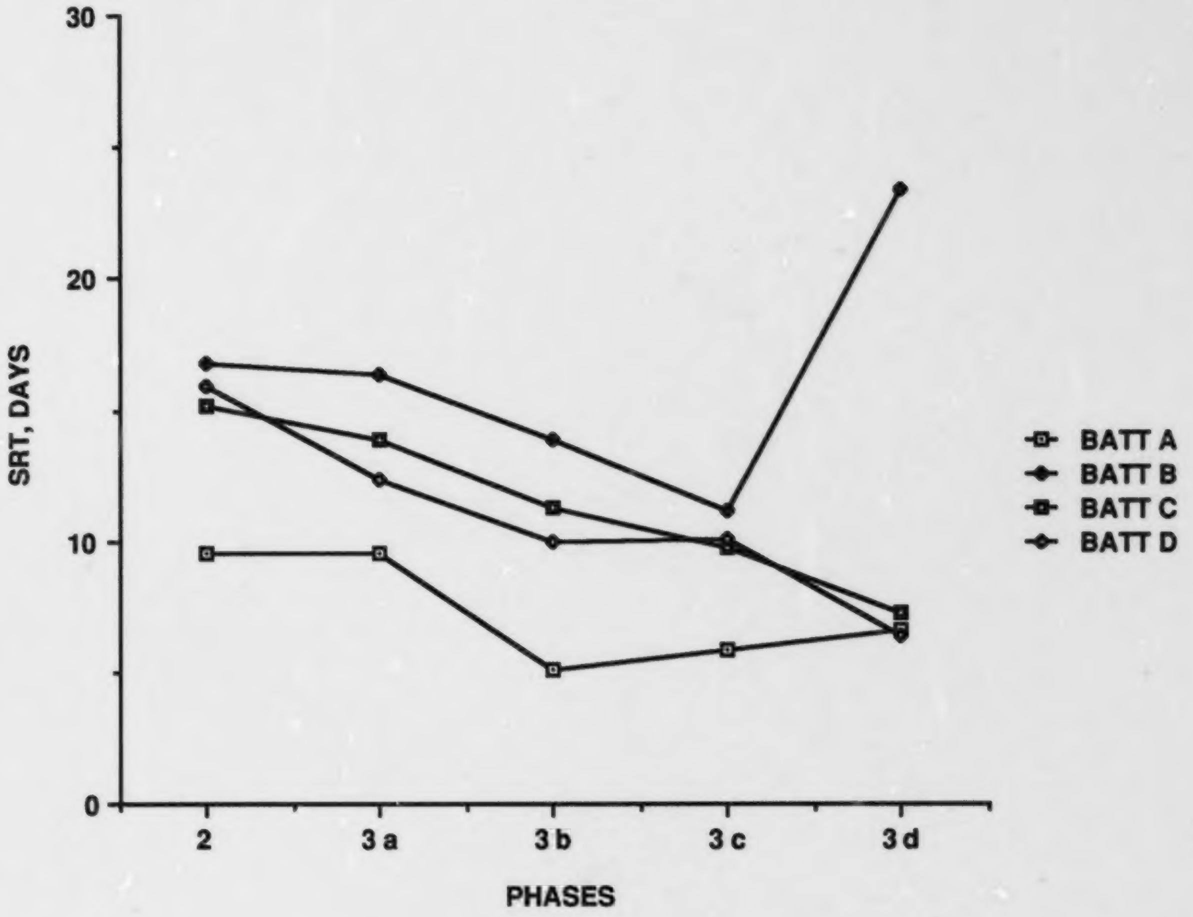


FIGURE 11 : AVERAGE SOLIDS RETENTION TIME OF CONTROL AND EXPERIMENTAL SECTIONS AERATION BATTERIES

The SRTs are not independently controllable and depend in part on the design of the battery. SRTs for Batteries C and D, which comprise the experimental section, were extremely close together for each phase although there was a downward drift in successive phases. Batteries A and B, which comprise the control section, also drifted downward, bracketing the SRTs for Batteries C and D for all of the phases. Battery B, which is identical with Batteries C and D, showed almost the same SRTs except during Phase 3d, when it inexplicably increased. Battery A showed the lowest SRTs. for Phase 3d, its SRT was almost the same as for Phase C and D.

For the control phase (no. 2), one would expect all the batteries to have about the same SRTs. Batteries B, C, and D were of the same size. The SRT for Battery A is much lower but this could be an artifact of the different size and design. One can then look to see whether increasing the recycle of digested sludge (Phase 3a to 3d) caused the SRT for the C and D batteries to shift upwards or downwards relative to the "bracketing" results for Batteries A and B. There appears to be no significant shifts until Phase 3d. For this phase, batteries A and B behave erratically relative to one another. There is no way to make a comparison of C and D relative to the controls for Phase 3d. Based on the recycling experiments of Phase 3a through 3c, there is no significant effect of recycling on SRT.

Mixed Liquor Suspended and Volatile Solids Concentration in Batteries--

The MLSS and MLVSS concentration (average for the two batteries in each section) maintained in the control and experimental sections are given in Figures 12 and 13. The actual MLSS concentration in all the batteries was able to be maintained within the range of 2,434 to 3,009 mg/L during the various phases (See Appendix Table E-1). Approximately 75 percent of these MLSS are volatile, thus, the MLVSS were within the range of 1,860 to 2,361 mg/L.

The average MLSS concentration as maintained in the control and experimental sections was within 2,500 to 3,000 mg/L throughout the course of the study (Figure 12). The average MLVSS concentration varied within a range of about 1,950 to 2,300 mg/L as shown in Figure 13.

Suspended Solids Removal Efficiency of Control and Experimental Sections--

The concentration of suspended solids in the raw sewage, primary effluent, and secondary effluent of the control and experimental sections is given in Figure 14 for Phases 2 and 3 (See also Appendix Table E-1).

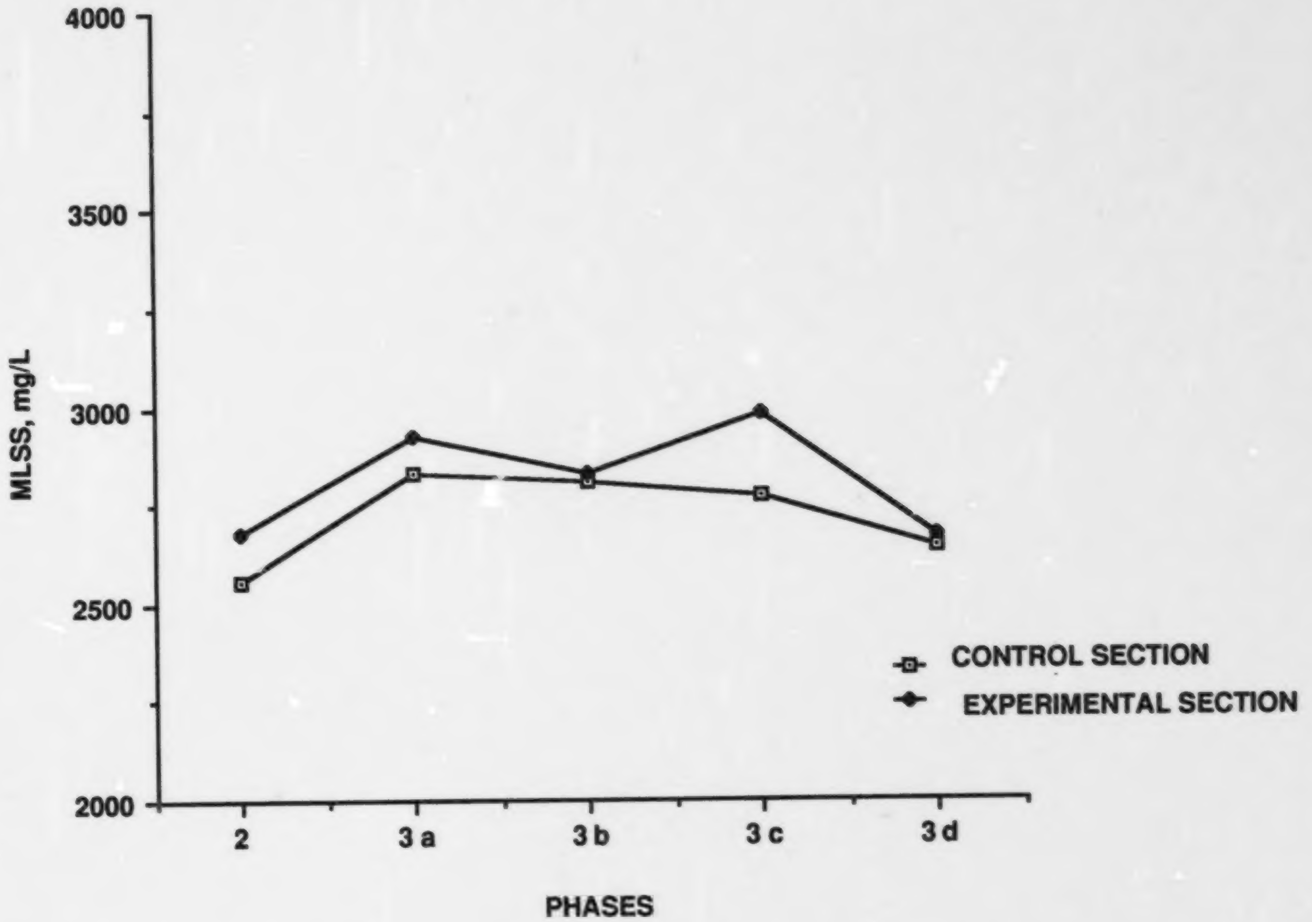


FIGURE 12 : AVERAGE MLSS CONCENTRATION IN CONTROL AND EXPERIMENTAL SECTIONS AERATION BATTERIES

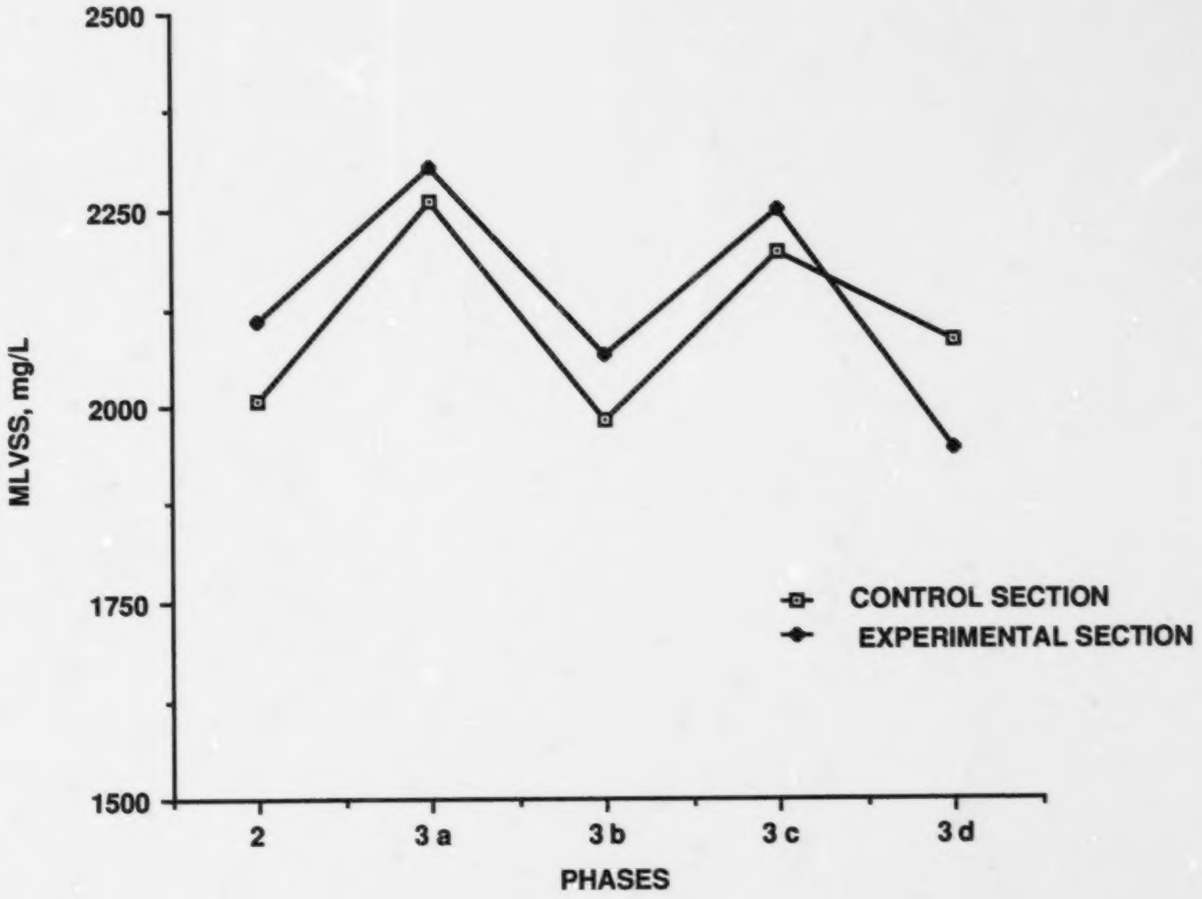


FIGURE 13 : AVERAGE MLVSS CONCENTRATION IN CONTROL AND EXPERIMENTAL SECTIONS AERATION BATTERIES

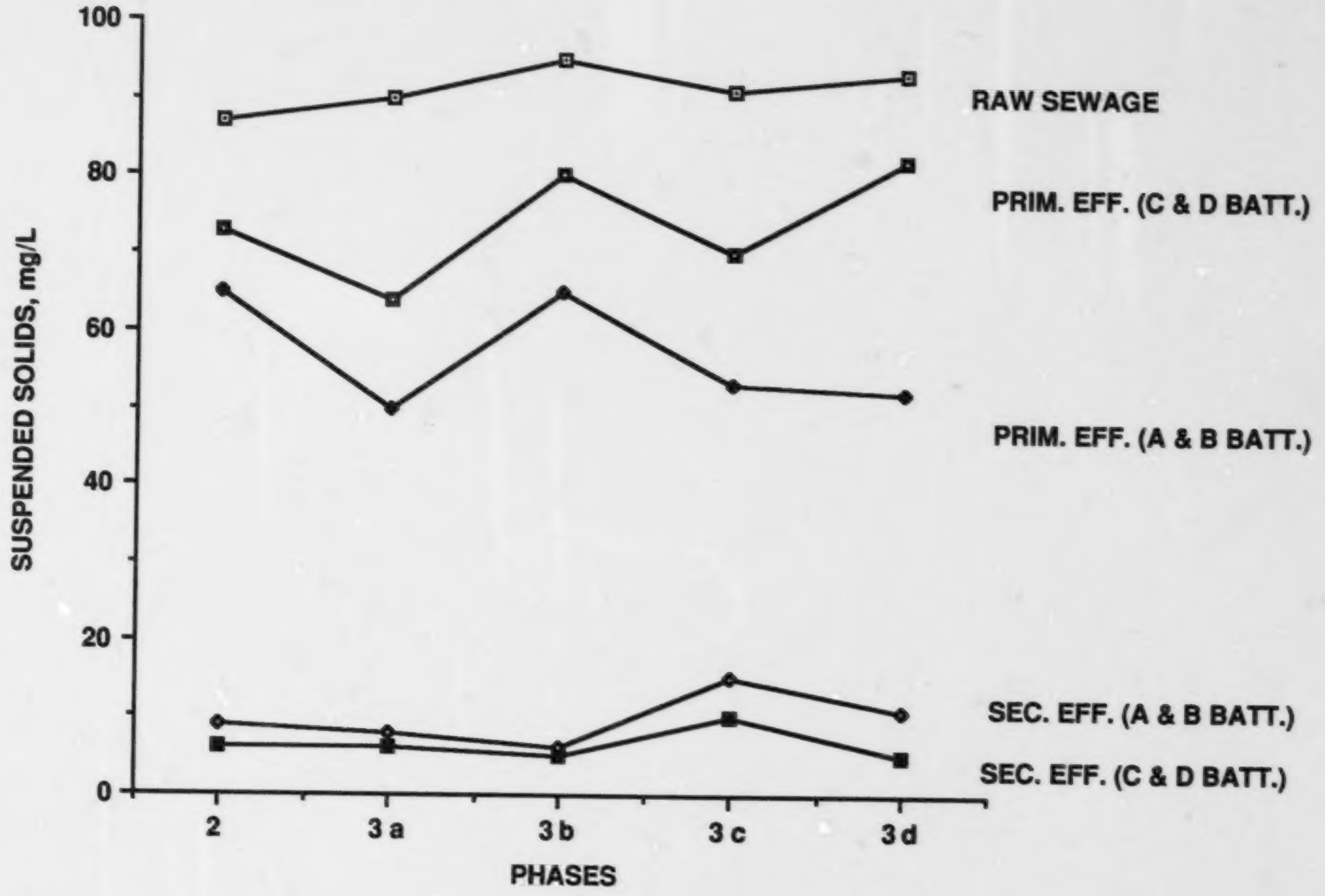


FIGURE 14 : AVERAGE SUSPENDED SOLIDS CONCENTRATION OF CONTROL AND EXPERIMENTAL SECTIONS

The results in Figure 14 show low suspended solids in the secondary effluent. The experimental section (C and D batteries) showed slightly lower suspended solids in the secondary effluent than the control section (A and B batteries) in all phases of the investigation. The recirculation of sludge that occurred in Phase 3a to 3d did not cause a deterioration of the quality of the effluent with respect to suspended solids.

The primary clarifiers for the control section (A and B batteries) appeared to perform better than the clarifiers for the experimental section (C and D batteries). However, it should be recalled that waste activated sludge is introduced into the primary clarifiers after the point that raw wastewater solids are introduced. To compare the primary clarifier performance, the two solids input streams - solids in the entering wastewater and the waste sludge - must be compared to the solids in the primary effluent stream. Table 3 compares the calculated percentage removal efficiencies for suspended solids of the control and experimental sections for all phases of the investigation.

The clarifiers for the control section (A and B) outperformed those for the experimental section (C and D). There were no significant trends. No deterioration or improvement in performance of the primary clarifiers for the experimental section was experienced in Phases 3c and 3d when recirculation of digested sludge to the aeration tanks was largest. Actually, there is no reason to anticipate an effect because the increase in recycling rate would only affect, if any, aeration tanks and the secondary clarifiers of the experimental section.

BOD Removal Efficiency of Control and Experimental Sections--

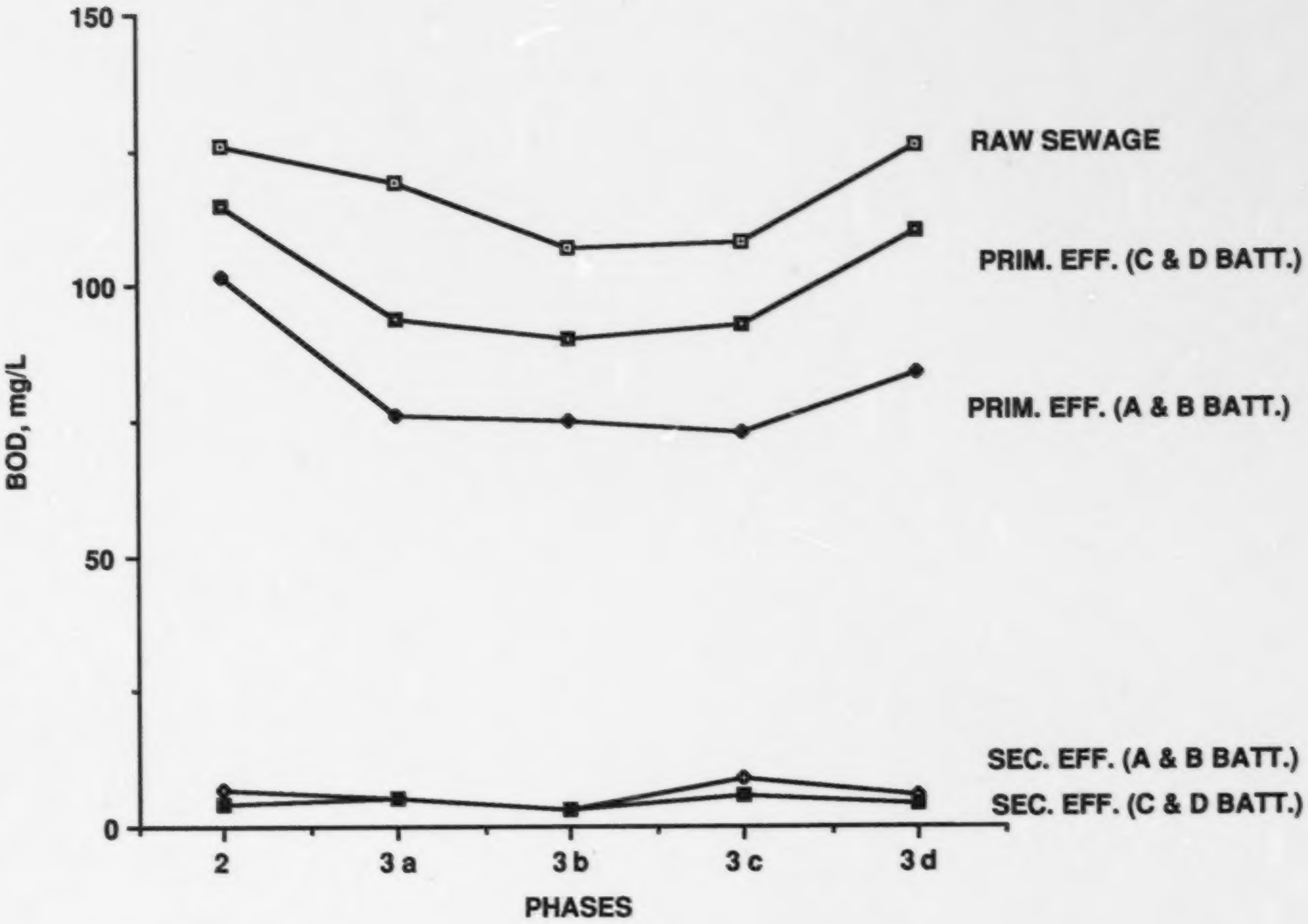
The mean values of BOD of raw sewage, primary effluent, and secondary effluent of the control and experimental sections of the Hanover Park WRP are given in Figure 15.

BODs leaving the primary clarifiers were about 40 mg/L lower than the raw sewage values for the control section (A and B) and about 20 mg/L lower for the experimental section (C and D).

A mass balance was not carried out on the primary clarifiers for BOD, because BODs were not determined on the waste sludges. In primary clarifiers, BOD removals generally are somewhat lower than suspended solids removals. If it is assumed that the clarifier efficiencies for BOD removal were about 50 percent, effluent BODs would have averaged about 50-60 mg/L if the waste sludges were not recirculated in the

TABLE 3. PERCENT REMOVAL OF SUSPENDED SOLIDS IN PRIMARY CLARIFIERS OF CONTROL AND EXPERIMENTAL SECTIONS

	Percent Removal of Suspended Solids	
Phase	Control Section Primary Clarifiers A and B	Experimental Section Primary Clarifiers C and D
2	64	58
3a	74	65
3b	71	60
3c	75	65
3d	74	70



FIGUERE 15 : AVERAGE BOD CONCENTRATION OF CONTROL AND EXPERIMENTAL SECTIONS primary clarifiers. The much higher BODs in the primary effluents from the control and experimental section indicate a considerable BOD contribution from the waste sludges. The waste sludges evidently were only partially removed by clarification, and thus contributed to the high BODs in the primary effluent.

The BODs for effluent from the secondary clarifiers were in the range of 3-9 mg/L for the control section and 3-6 mg/L for the experimental section. Percent removals for the total systems can be calculated from input raw sewage and final effluent BODs. For the control sections, removals ranged from 91.7 to 97.2 percent and from 94.2 to 97.7 percent for the experimental section. There are no trends indicating change in performance with increasing recycling of sludge from the digesters in the experimental section.

NH_4-N Removal Efficiency of the Control and Experimental Sections--

The profiles of NH_4-N in the raw sewage, primary effluent, and final effluent of the control and experimental sections are given in Figure 16. The NH_4-N in the primary effluent of the experimental section was higher than that of the control section. While its concentration was in the range of 12.4 to 16.9 mg/L in the primary effluent of the experimental section it was in the range of 10.7 to 15.0 mg/L in the control section.

The overall percent removal of NH_4-N was within the range of 91.0 to 98.6 percent in the control and experimental sections. The NH_4-N concentration of the secondary effluent was less than 1.2 mg/L in both of these sections indicating that the plant was nitrifying fully during all the phases. There were no significant differences between control and experimental sections.

Sludge Volume Index (SVI) of Mixed Liquor of Various Aeration Batteries--

A profile of the average SVI values of the different phases for the various aeration batteries is given in Figure 17). No distinct trends are observed in the SVI data. The changes in SVI values that were observed during the various phases were in the same direction and magnitude for both the control and experimental batteries. The recycling of thermophilic drawoff into the aeration batteries of the experimental section did not have an influence on SVI values.

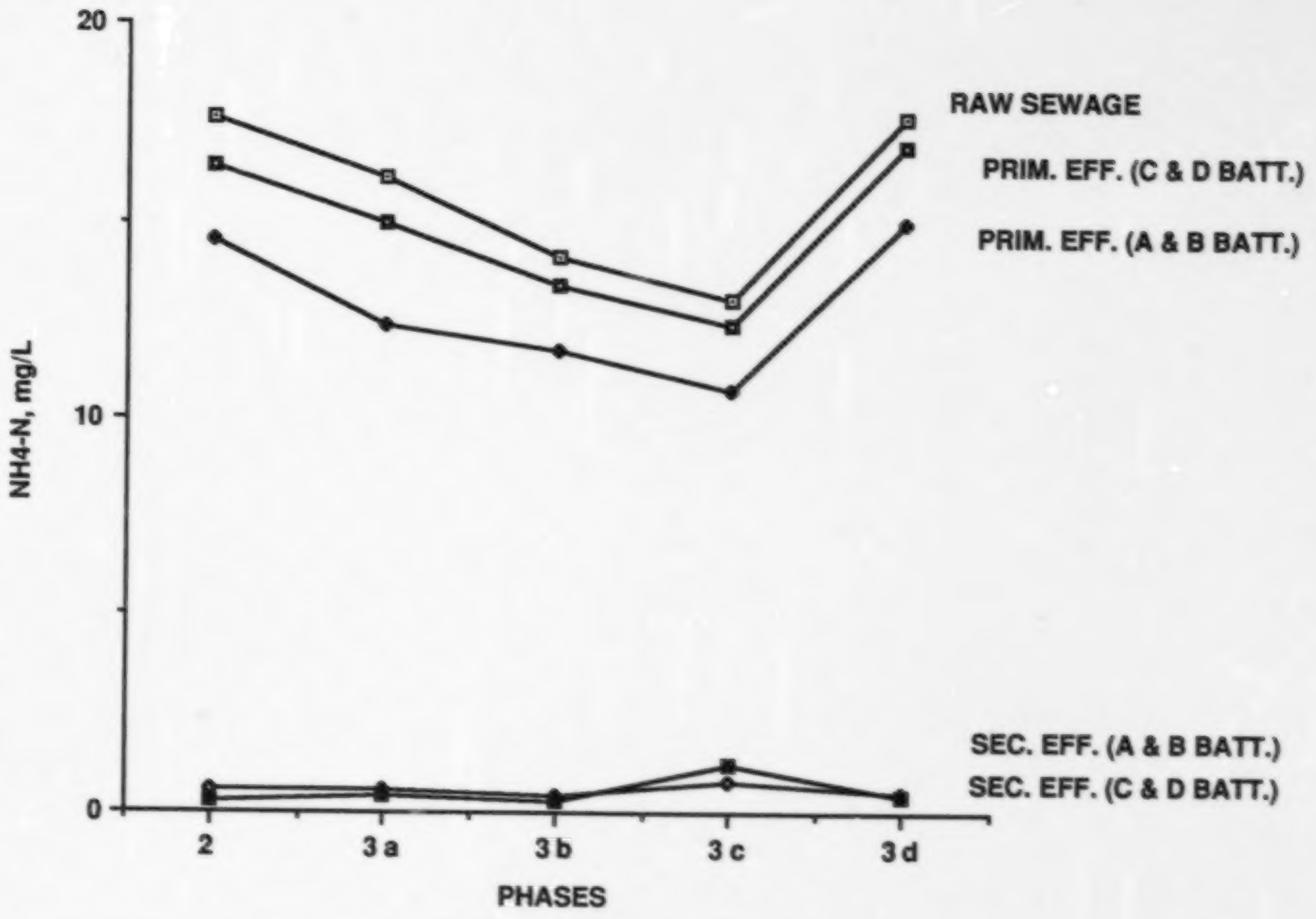


FIGURE 16 : AVERAGE NH4-N CONCENTRATION OF THE CONTROL AND EXPERIMENTAL SECTIONS

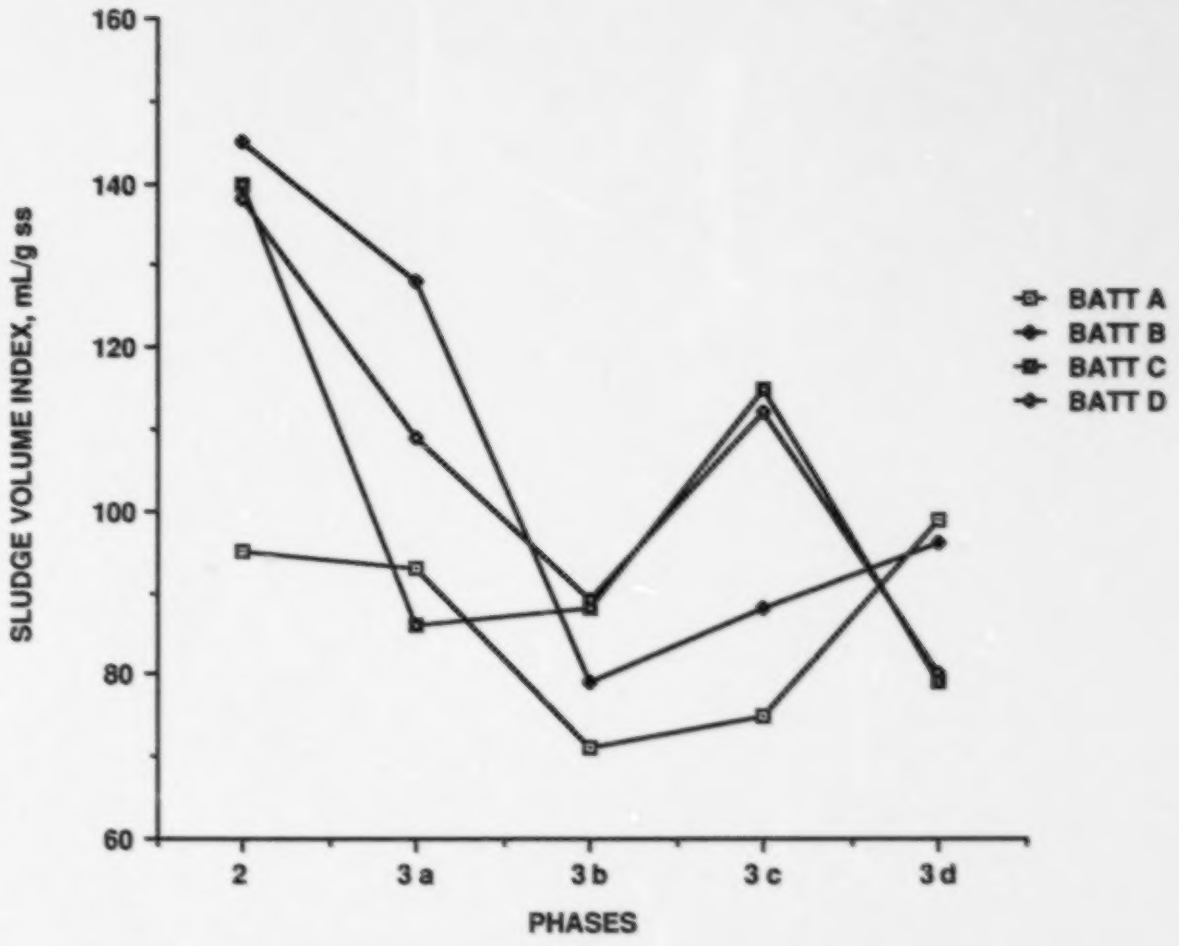


FIGURE 17 : PROFILE OF SLUDGE VOLUME INDEX IN DIFFERENT PHASES

Dissolved Oxygen Concentration and Oxygen Uptake Profiles of Mixed Liquors--

The dissolved oxygen concentration profiles of the aeration tanks of the control and experimental sections were taken at their inlet, midpoint, and outlet with a dissolved oxygen probe during Phases 3c and 3d. These are the subphases during which about 40 and 50 percent of the thermophilic sludge drawoff was recycled into the aeration batteries of the experimental section. A summary of these profiles is given in Table 4.

From a comparison of the control and experimental section DO profile data, it can be seen that the dissolved oxygen concentration in the experimental section is not depressdue to the recycling of the thermophilic sludge drawoff.

A comparison of oxygen uptake rates of the aeration tank mixed liquors of the control and experimental sections (Table 5) did not reveal any significant trends to warrant a conclusion that the recycling of thermophilic sludge drawoff into the aeration tanks of the experimental section caused increased oxygen uptake rates.

Microbiological Examination of Mixed Liquors--

Data on the total length of filaments, the number of flagellates, amoebae, free and stalked ciliates that are contained in the mixed liquors sampled from the various batteries batteries are given in Tables 6 and 7. These data did not indicate any definite trends to denote any meaningful differences between the mixed liquors of control and experimental section aeration batteries. Hence, it appears that the recycling of thermophilic sludge drawoff into the aeration tanks of Batteries C and D had no significant impact on altering the profile of the organisms examined in this study.

Overall Performance of the Control and Experimental Sections

An examination of Phase 2 data (Figures 14, 15, and 16) indicated that the control and experimental sections of the Hanover Park WRP performed comparably in yielding a secondary effluent of similar quality with respect to BOD, NH_4-N, and suspended solids. A review of the plant performance records indicated that the overall performance of the plant observed during this study period was comparable to its performance during the year prior to this study, as far as meeting the standards such as BOD, SS, and NH_4-N listed on the National Pollutant Discharge Elimination System (NPDES) permit issued for this WRP. The recycling of the digester draw to the experimental section of the Hanover Park WRP appeared to have

TABLE 4. DISSOLVED OXYGEN CONCENTRATION (mg/L) PROFILE IN THE AERATION TANKS OF THE CONTROL AND EXPERIMENTAL SECTIONS*

Phase	Aeration Tanks D.O. Concentration, mg/L				
		Control Section			
		Battery A		Battery B	
3c		Tank 1	Tank 2	Tank 3	Tank 4
	Inlet	2.7-6.7	2.2-6.6	1.9-6.3	1.7-7.4
	Mid	3.1-7.4	2.2-7.6	1.8-6.4	1.8-8.0
	Outlet	3.1-8.4	2.2-7.4	3.5-8.8	3.1-9.0
		Experimental Section			
		Battery C		Battery D	
		Tank 5	Tank 6	Tank 7	Tank 8
	Inlet	1.0-7.5	1.2-7.1	1.8-8.1	1.5-8.4
	Mid	2.1-8.4	1.8-8.6	2.0-9.2	2.5-8.8
	Outlet	3.2-10.0	2.8-9.2	2.7-9.9	3.5-9.7
		Control Section			
		Battery A		Battery B	
3d		Tank 1	Tank 2	Tank 3	Tank 4
	Inlet	1.1-6.5	2.5-6.3	1.2-5.9	1.0-5.3
	Mid	1.3-6.7	1.4-7.4	1.2-7.1	1.0-6.7
	Outlet	2.5-7.8	1.4-8.4	2.4-9.6	1.8-9.0
		Experimental Section			
		Battery C		Battery D	
		Tank 5	Tank 6	Tank 7	Tank 8
	Inlet	0.9-6.1	1.7-6.9	1.2-8.1	1.1-8.4
	Mid	1.9-6.9	1.8-8.6	1.5-9.2	1.1-8.8
	Outlet	3.1-9.8	2.4-9.2	2.2-9.9	1.5-9.7

*Values indicated are ranges.

TABLE 5. OXYGEN UPTAKE RATES OF THE MIXED LIQUORS OF CONTROL AND EXPERIMENTAL SECTIONS AREATION TANKS

Phase	Tank No.*	Inlet end	Mid Point	Outlet end
		mg/(L. g MLSS)		
2	1	6.4-36.1	5.7-30.7	4.4-25.5
	2	6.8-28.9	5.9-19.1	6.8- 9.5
	3	9.2-31.1	7.4-29.2	7.9-11.7
	4	5.9-27.0	5.9-22.6	7.0-11.2
	5	5.4-25.6	8.1-20.3	2.7-10.4
	6	4.2-26.0	2.7-22.2	2.4-10.5
	7	4.4-26.9	4.4-23.2	2.9- 9.8
	8	6.3-28.6	4.7-23.8	3.0-11.2
3c	1	9.7-19.5	9.2-13.0	5.3-11.8
	2	11.2-16.5	8.6-12.4	9.2-13.1
	3	12.3-23.2	10.4-21.0	9.6-14.6
	4	9.3-22.7	10.6-16.5	9.9-14.6
	5	10.8-24.9	8.1-14.6	8.2-12.5
	6	11.5-23.0	9.6-14.1	9.7-12.9
	7	13.2-21.8	9.8-16.2	10.2-22.3
	8	11.3-31.8	10.9-31.7	8.7-12.7
3d	1	7.8-21.5	6.9-22.8	4.6-17.1
	2	4.9-19.1	3.1-16.0	6.6-10.8
	3	5.4-16.4	3.1-14.1	5.4-14.6
	4	17.4-21.3	15.7-21.4	8.7-18.9
	5	13.5-25.2	8.4-19.9	4.6- 9.2
	6	8.4-21.1	4.9-21.4	4.5-11.2
	7	10.4-20.9	6.1-18.9	5.1-11.8
	8	13.5-25.1	11.7-23.5	7.1-14.0

*Tank Nos. 1,2,3, and 4 - Control Section.
Tank Nos. 5,6,7, and 8 - Experimental Section.

TABLE 6. MICROBIOLOGICAL FLORA OF MIXED LIQUORS
AERATION BATTERIES A & B (CONTROL SECTION)

Organism	Phase 2		Phase 3a		Phase 3c		Phase 3d	
	A	B	A	B	A	B	A	B
Amoeba (Naked)	1240 (0-5042)	1220 (0-5042)	1366 (0-2521)	1541 (0-3362)	1345 (0-2241)	224 (0-1120)	560 (0-1681)	764 (0-2801)
Amoeba (Naked)	60 (0-420)	120 (0-420)	120 (0-420)	280 (0-840)	2241 (0-3921)	1457 (0-2801)	407 (0-1681)	51 (0-560)
Flagellates	7223 (0-19749)	4261 (0-14707)	9245 (3362-17228)	4832 (420-8824)	5154 (560-12685)	4705 (0-12324)	6909 (0-27057)	6287 (0-40334)
Free Ciliates	1560 (420-3931)	2341 (420-7143)	2837 (1261-5883)	1681 (840-2521)	2065 (560-4482)	5154 (2801-8403)	1884 (0-3921)	2699 (0-5602)
Stalked Ciliates	6422 (0-27450)	1100 (0-3782)	1471 (0-2101)	1120 (0-2520)	1793 (0-6722)	1793 (0-3921)	5245 (0-31931)	9500 (0-34172)
Filaments	ND	ND	12.9 (5.7-25.0)	5.3 (2.9-7.3)	3.5 (0.805.7)	6.9 (2.0-16.6)	15.3 (5.9-42.0)	8.3 (1.5-23.8)

Note: All values are counts/ML except filaments which are meters/mL.
ND=Not Determined.

TABLE 7. MICROBIOLOGICAL FLORA OF MIXED LIQUORS
AERATION BATTERIES C & D (EXPERIMENTAL SECTION)

Organism	Phase 2		Phase 3a		Phase 3c		Phase 3d	
	C	D	C	D	C	D	C	D
Amoeba (Naked)	1860 (0-4202)	1898 (0-2521)	315 (0-840)	210 (0-840)	981 (0-2241)	336 (0-1120)	1058 (560-2241)	1307 (0-5602)
Amoeba (Testate)	480 (0-2101)	360 (0-1261)	945 (0-2101)	1050 (420-2101)	2017 (0-3361)	1568 (0-3361)	560 (0-1681)	1058 (0-5602)
Flagellates	3041 (0-5463)	5122 (0-20590)	11135 (0-31095)	3047 (0-5883)	4033 (1120-10084)	3361 (0-10084)	330500 (0-148453)	3548 (0-22408)
Free Ciliates	2171 (0-5042)	1744 (0-6723)	2837 (1681-3782)	3571 (840-6723)	4930 (1120-11764)	5490 (1681-13445)	2988 (560-7843)	2633 (560-6722)
Stalked Ciliates	2321 (0-5883)	3321 (0-5883)	2626 (840-5883)	3152 (420-7984)	5266 (0-20727)	11540 (2241-38094)	1618 (0-7283)	1805 (0-5042)
Filaments	ND	ND	4.7 (0.8-8.7)	5.4 (2.2-10.1)	13.8 (2.2-35.6)	4.8 (1.8-8.5)	9.5 (1.1-34.3)	13.3 (1.6-54.4)

Note: All vaules are counts/ML except filaments which are meters/mL.
ND=Not Determined.

no discernible adverse or beneficial effects on the quality of the effluent discharged from the plant as far as these NPDES standards are concerned.

Waste Activated Sludge Production in the Aeration Batteries--

In this study, hydraulic residence times were approximately equal and attempts were made to maintain the MLSS concentration in all the aeration batteries at an equal level by wasting appropriate quantities of activated sludge. If similar operational protocols are employed and the same primary effluent is processed through the various aeration batteries, one would expect that an equal mass of activated solids would be wasted per unit volume of sewage processed from these batteries to maintain an equal concentration of MLSS in the aeration batteries. However, if there are dissimilarities in the operational protocols employed, or dissimilarities in the efficiency of the various unit processes (e.g. differences in settling tank efficiencies), then the mass of activated sludge solids wasted from the various aeration batteries would be different for maintaining an equal MLSS concentration in them. In any event, the mass of activated sludge solids wasted can be termed as the net sludge production (synthesis) per unit volume of sewage flow processed, mass of BOD exerting substances fed, or mass of volatile solids processed through the system.

In order to further compare the performance of the control and experimental section aeration batteries under the operational protocols employed in this study, activated sludge solids production in the various aeration batteries, as explained above, was evaluated. This waste activated sludge production was computed and expressed in terms of grams of SS wasted per m^3 of sewage processed (Figures 18, 19), grams of SS wasted per kg of BOD processed (Figures 20,21), and grams of SS wasted per kg of VSS fed to the aeration batteries through the primary effluent (Figures 22, 23).

Figures 18, 20, and 22, show results for individual batteries. Figure 19,21, and 23 show the results for the sections (control is average of Battery A and B, experimental section is average of Battery C and D).

The three figures for the sections (Figures 19, 21, and 23) show poor agreement between control and experimental sections even for Phase 2 when there was no recirculation of digested sludge. One can examine the difference between the curves as more sludge is recirculated (Phases 3a and 3d), and see whether the increased recirculation causes the curves to diverge or come together. There is no clear evidence of any significant change. The erratic behavior for Phase 3d makes it necessary to disregard this point.

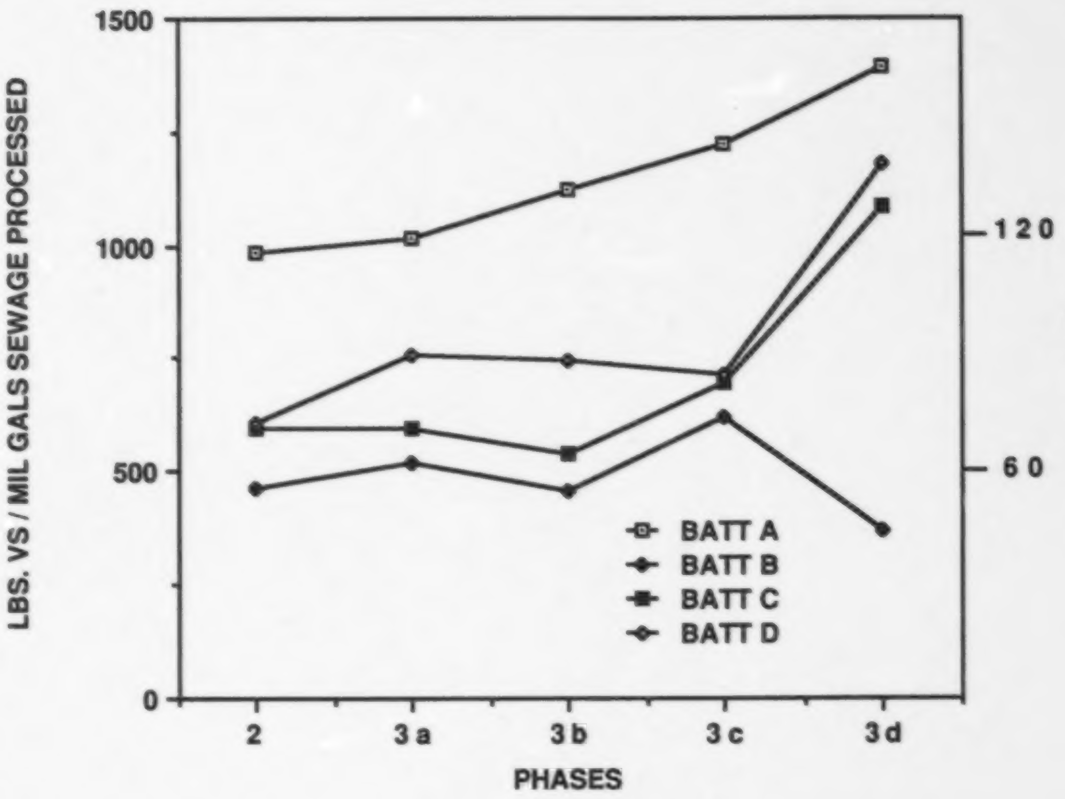


FIGURE 18 : WASTE ACTIVATED SLUDGE PRODUCTION OF AERATION BATTERIES PER FLOW TREATED

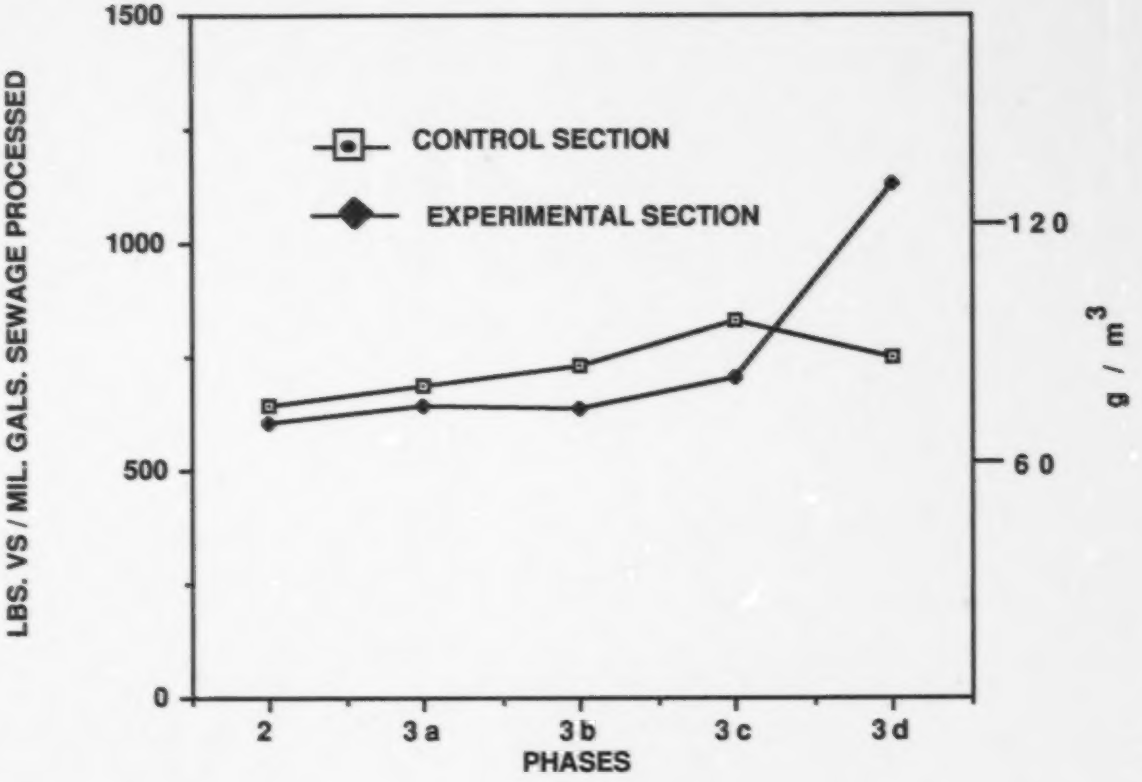


FIGURE 19 : WASTE ACTIVATED SLUDGE PRODUCTION OF CONTROL AND EXPERIMENTAL SECTIONS PER SEWAGE FLOW PRCESSED

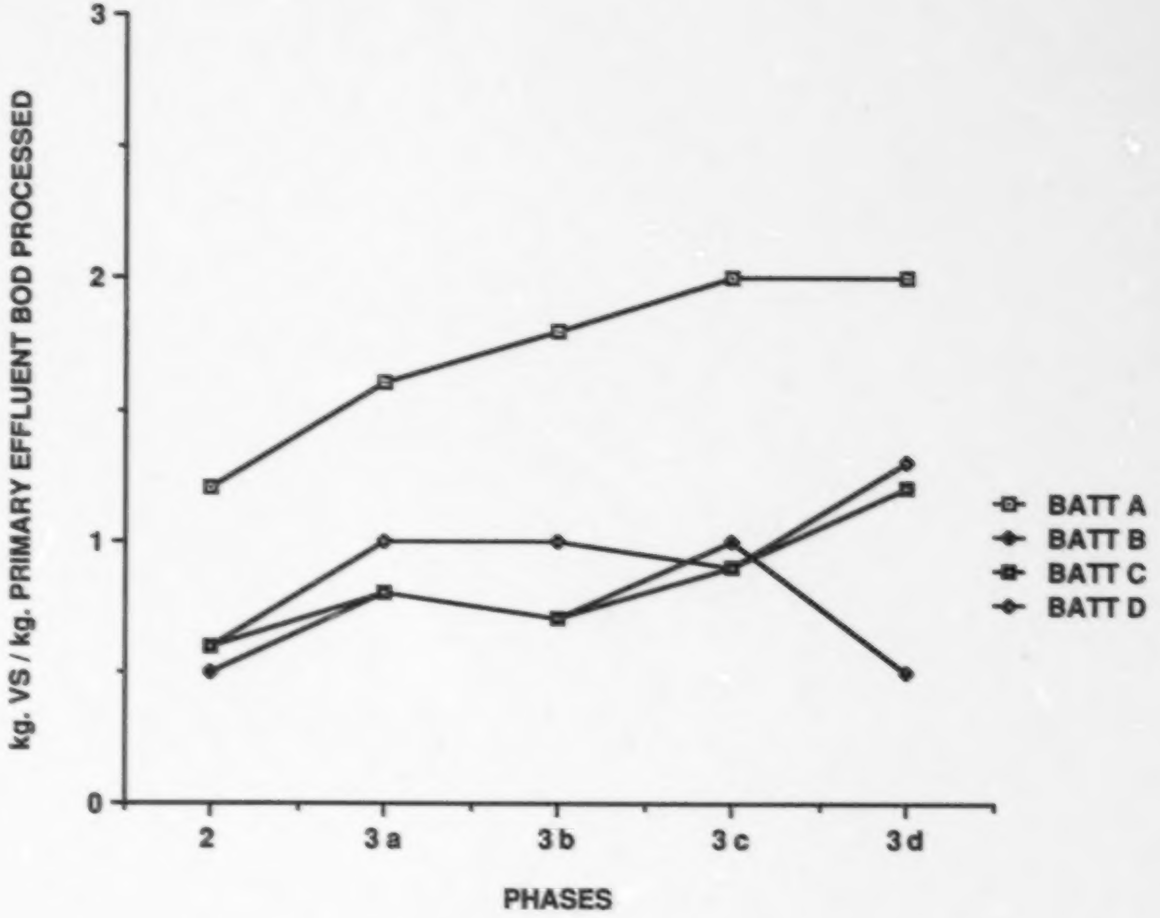


FIGURE 20 : WASTE ACTIVATED SLUDGE PRODUCTION OF AERATION BATTERIES PER PRIMARY EFFLUENT BOD PROCESSED

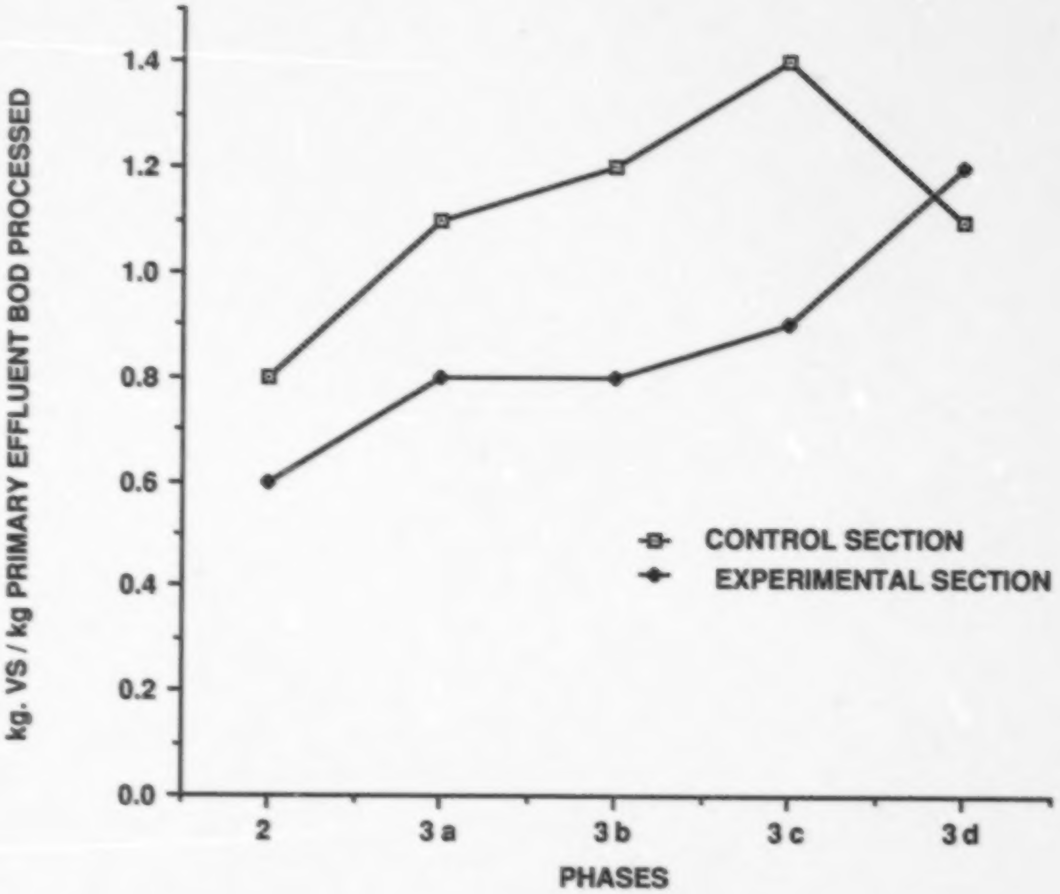


FIGURE 21 : WASTE ACTIVATED SLUDGE PRODUCTION OF CONTROL AND EXPERIMENTAL SECTIONS PER PRIMARY EFFLUENT BOD PROCESSED

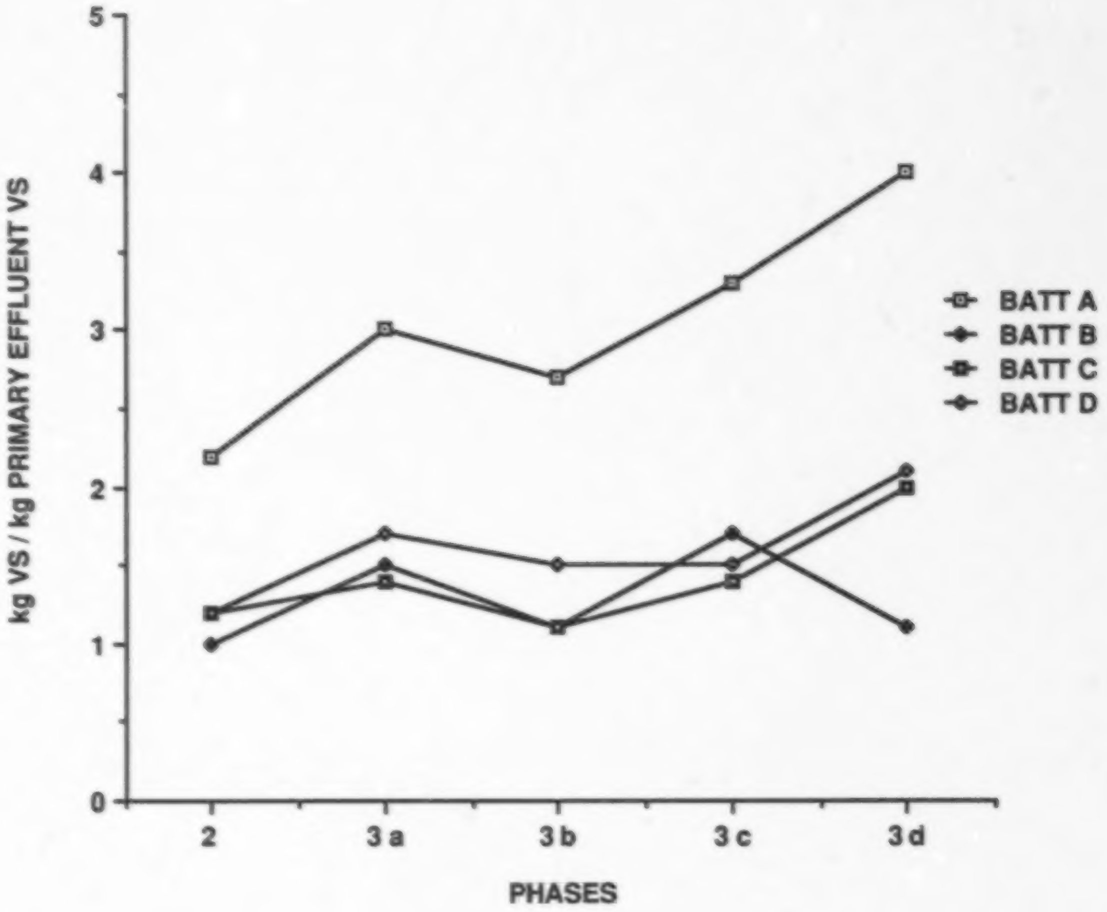


FIGURE 22 : WASTE ACTIVATED SLUDGE PRODUCTION OF AERATION BATTERIES PER PRIMARY EFFLUENT VOLATILE SOLIDS PROCESSED

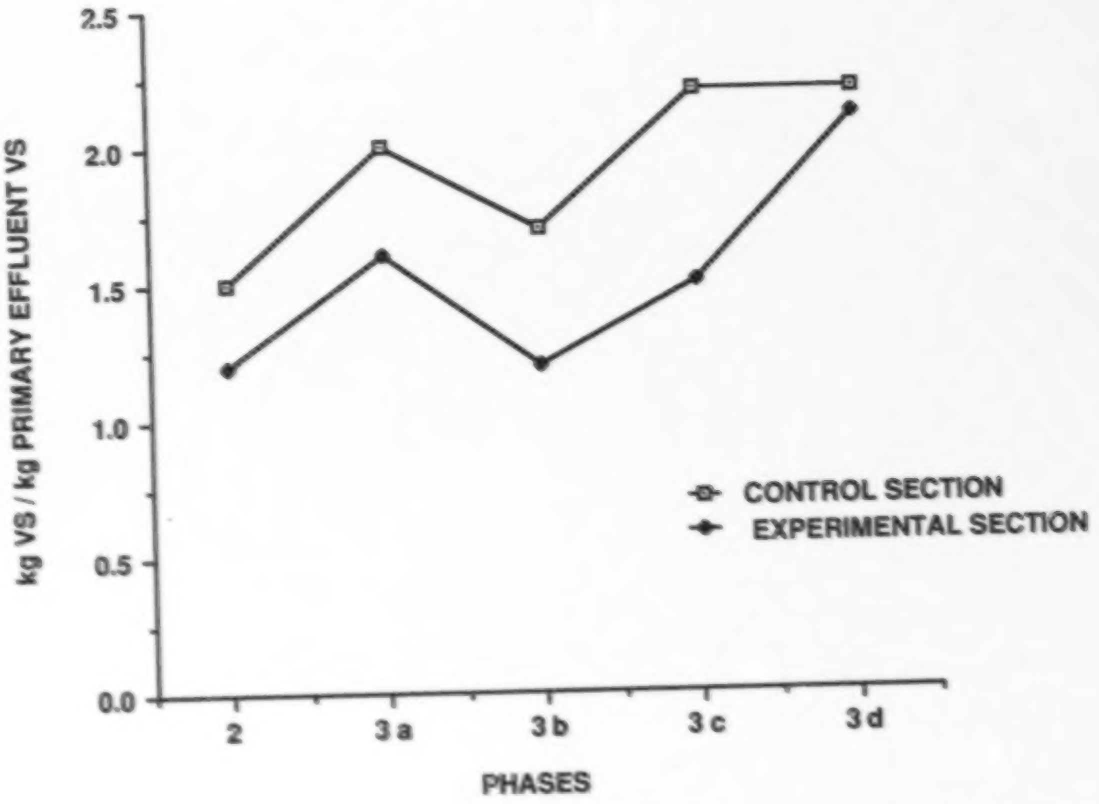


FIGURE 23 : WASTE ACTIVATED SLUDGE PRODUCTION FROM CONTROL AND EXPERIMENTAL SECTIONS PER PRIMARY EFFLUENT VS PROCESSED

More is revealed when the batteries are considered separately (Figures 18, 20, and 22). Battery A is seen to be far different from the others even at the baseline condition (Phase 2). The sludge production per unit of BOD processed is far greater for Battery A than is common experience with the activated sludge process (range is 1.2 - 2 kg VS/kg BOD processed for Battery A versus a more usual range of 0.6 - 1.0 kg VS/kg BOD processed). All the other batteries show more reasonable production rates. Batteries B, C, and D show comparable sludge production rates in all three phases except for Phase 3d. Ignoring results for Phase 3d, it appears that recirculation of digested sludge does not increase or decrease the amount of sludge wasted.

The variability in waste activated sludge production rates in the control and experimental sections is further discussed in this report in the section dealing with the mass balance of volatile solids around the aeration tanks.

Performance of Digesters

As described earlier, the two digesters in the control section (Digester Nos. 1 and 2) were operated in series at 35°C. In the experimental section the two digesters (Digester Nos. 3 and 4) were also operated in series with the exception that Digester No. 4 was operated at an average temperature of 53°C through all phases of the study.

Prior to the initiation of this study, Digester No. 4 was operated at the Hanover Park WRP as a mesophilic digester. This digester was converted to a thermophilic digester according to the procedure described in the "Materials and Methods" section.

Since it is not possible to change the physical configuration of the digesters and a decision was made to digest all the primary and WAS produced in the control and experimental sections of the Hanover Park WRP, the digesters were operated by processing all the sludge that was received by the primary digesters (Digester Nos. 1 and 3). As a consequence of this the detention times and loading rates of the digesters not be kept equal. The average loading rates and detention times of the digesters in the control and experimental sections during the various equilibrium phases are given in Table 8.

The data from Table 8 indicate that the detention time of the experimental section digesters (Digester Nos. 3 and 4) decreased progressively during Phase 2 through 3d due to an increase in the recycling rate of the thermophilic sludge drawoff to the aeration tanks of the experimental section. Whatever volume of sludge that was recycled from Digester No. 4 drawoff to the experimental section aeration batteries came

TABLE 8. RANGE OF LOADING RATES AND DETENTION TIMES OF DIGESTERS DURING THE VARIOUS PHASES

	Phases				
	2	3a	3b	3c	3d
			Control Section		
Digester No. 1					
Loading Rate $kg/m^3/d$ ($lbs/ft^3/d$)	2.08 (0.13)	2.08 (0.13)	1.76 (0.11)	2.08 (0.13)	1.92 (0.12)
Detention Time (days)	9.9	11.7	12.3	11.7	11.9
Digester No. 2					
Loading Rate $kg/m^3/d$ ($lbs/ft^3/d$)	1.28 (0.08)	1.12 (0.07)	1.12 (0.07)	1.28 (0.08)	1.44 (0.09)
Detention Time (days)	9.7	11.8	11.4	10.6	9.6
			Experimental Section		
Digester No. 3					
Loading Rate $kg/m^3/d$ ($lbs/ft^3/d$)	2.72 (0.17)	3.36 (0.21)	3.04 (0.19)	4.17 (0.26)	4.65 (0.29)
Detention Time (days)	8.1	7.9	6.5	5.1	4.7
Digester No. 4					
Loading Rate $kg/m^3/d$ ($lbs/ft^3/d$)	1.60 (0.10)	1.92 (0.12)	1.92 (0.12)	2.40 (0.15)	3.36 (0.21)
Detention Time (days)	8.2	7.4	6.0	5.3	4.1
Sludge Recycling Rate (%)+	0	13.1	29.1	40.4	50.7

+Percent volume of thermophilic digester draw recycled to aeration battery C.

back to the Digester No. 3 eventually as was confirmed by a volume balance computation carried around the aeration tanks and the volume of sludge withdrawn from Digester No.4 (See "Mass Balance of Volatile Solids around Various Unit Processes of the Control and Experimental Sections of the Hanover Park WRP" page --- of this report).

Start-up and Equilibration of Thermophilic Digester--

The start-up and equilibration of the thermophilic digester (Digester No. 4) began in June 1985. The profile of the temperature and volatile acids in this digester during the start-up and equilibration modes is given in Figure 24. Although there was an upset during July 1985 in the thermophilic digester, it was quickly corrected by stopping the feed to the digester, increasing the temperature by 1°C per week instead of 1°C every two days, and by increasing the feed rate gradually to the normal loading rate. This procedure brought the digester under control and the temperature was maintained stably at 53°C without any further upsets throughout the study period.

Odors at the Hanover Park WRP During the Study--

After the start-up of the thermophilic digester, operating personnel at the Hanover Park WRP indicated that the drawoff from the thermophilic digester exhibited an odor that is distinctly different from the mesophilic sludge drawoff and is not pleasing. This was qualitatively verified by the project personnel as well.

The procedure for disposing of the portion of the thermophilic sludge drawoff, which was not recycled into the aeration batteries, was to apply it on the farm adjacent to the Hanover Park WRP along with the mesophilic sludge drawoff. On many occasions, when the prevailing winds blew towards the housing development adjacent to the WRP, complaints were received from the home owners by the plant manager about the malodors of the sludge. Similarly, complaints were registered registered by the management of the elementary school located adjacent to the plant about the bad odors released from the treatment facility.

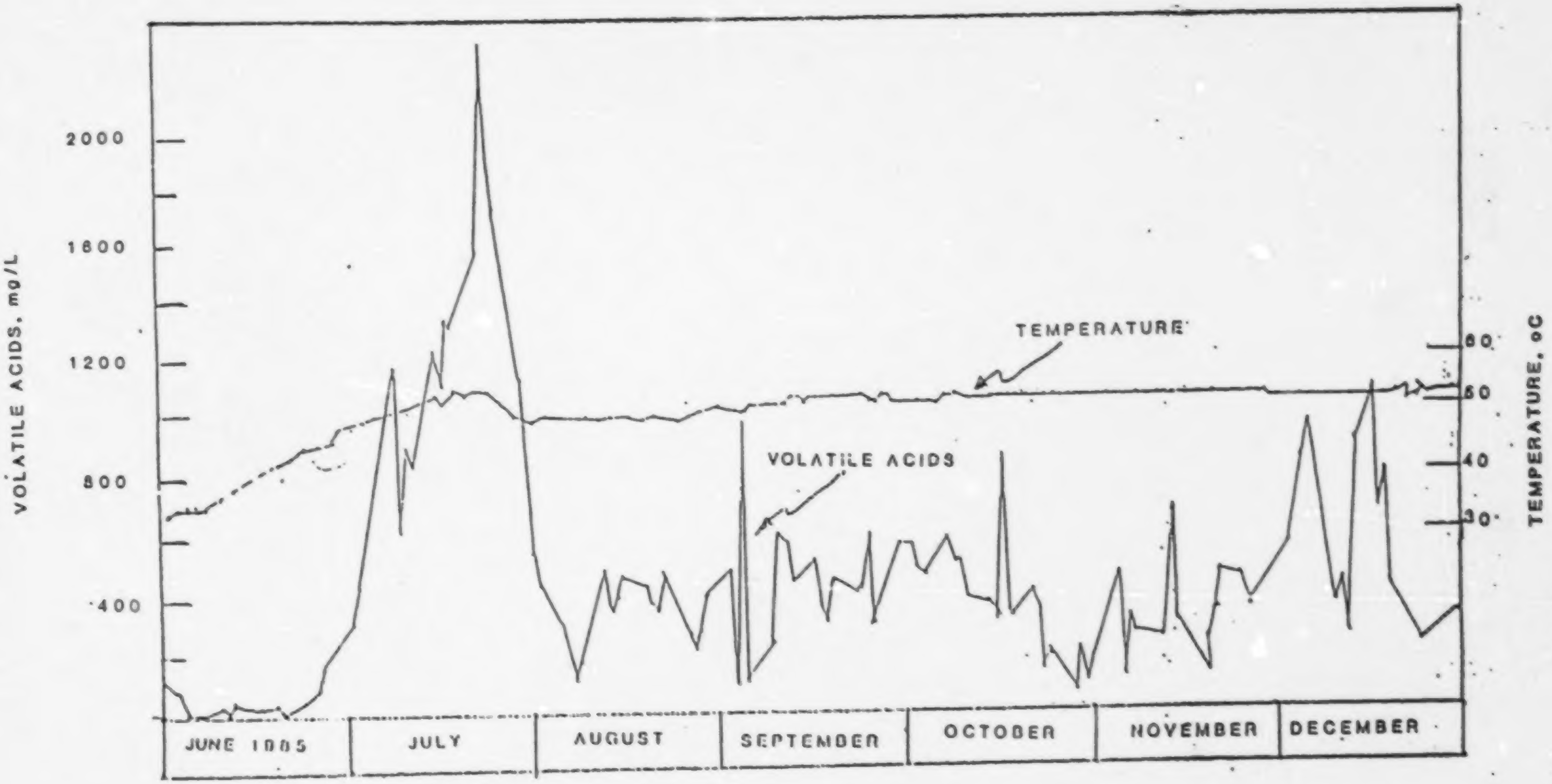
The Hanover Park WRP has made it a practice to spray potassium permanganate whenever thermophilic sludge drawoff is applied onto the farm to mitigate the odor problem.

Digester Performance Data

The digester performance data are summarized for Phases 2 through 3d along with the data presented on the other aspects of the study, in the Appendix Table E-1.

FIGURE 24

VOLATILE ACIDS AND TEMPERATURE PROFILE OF DIGESTER 4



The fate of pH, alkalinity, volatile acids, ammonia and total kjeldahl nitrogen (TKN) of the feeds and draws of the control and experimental digesters for Phases 2 through 3d are discussed below.

Fate of pH in Digesters--

The profile of pH of the feeds and drawoffs of the control and experimental section digesters during the various phases are given in Figures 25 and 26. The pH of the control and experimental digester feeds are acidic within the range of 5.4 to 6.2. The drawoffs of the control section digesters had a pH within the range of 7.3 to 7.4.

Although the pH of the Digester No. 3 drawoff sludge was within the range of 7.1 to 7.3, it was increased by about 0.5 units by passage through thermophilic digestion in Digester No. 4.

Fate of Alkalinity in Digesters--

The alkalinity of the feeds to the control and experimental digesters and their drawoffs is given in Figures 27 and 28.

The average alkalinity of the feeds to Digester No. 1 was within the range of 528 to 779 mg/L. When these feeds underwent digestion, the alkalinity increased and the drawoffs for Digester No. 2 had average alkalinity values in the range of 1,778 to 2,600 mg/L. A similar trend was also noticed in the experimental digesters.

Fate of Volatile Acids in Digesters--

The average volatile acid content of the feeds and drawoffs during the various phases for the control and experimental digester systems are given in Figures 29 and 30.

The average volatile acid concentration of the feed to Digester No. 1 of the control section was in the range of 718 to 1,768 mg/L. This level of volatile acids was reduced to the range of 18 to 86 mg/L in the drawoff of Digester No. 2. A similar trend also was noted in the experimental digesters although the mean volatile acid content of the drawoff from Digester No. 4 was higher than that of Digester No. 2 of the control section; the difference was possibly due to the effect of thermophilic temperatures. The volatile acid content of Digester No. 4 was in the range of 89 to 233 mg/L. These concentrations were considerably lower than those encountered during the start-up and equilibration of this digester at the beginning of the study. During the study no significant accumulation of volatile acids was observed in the thermophilic

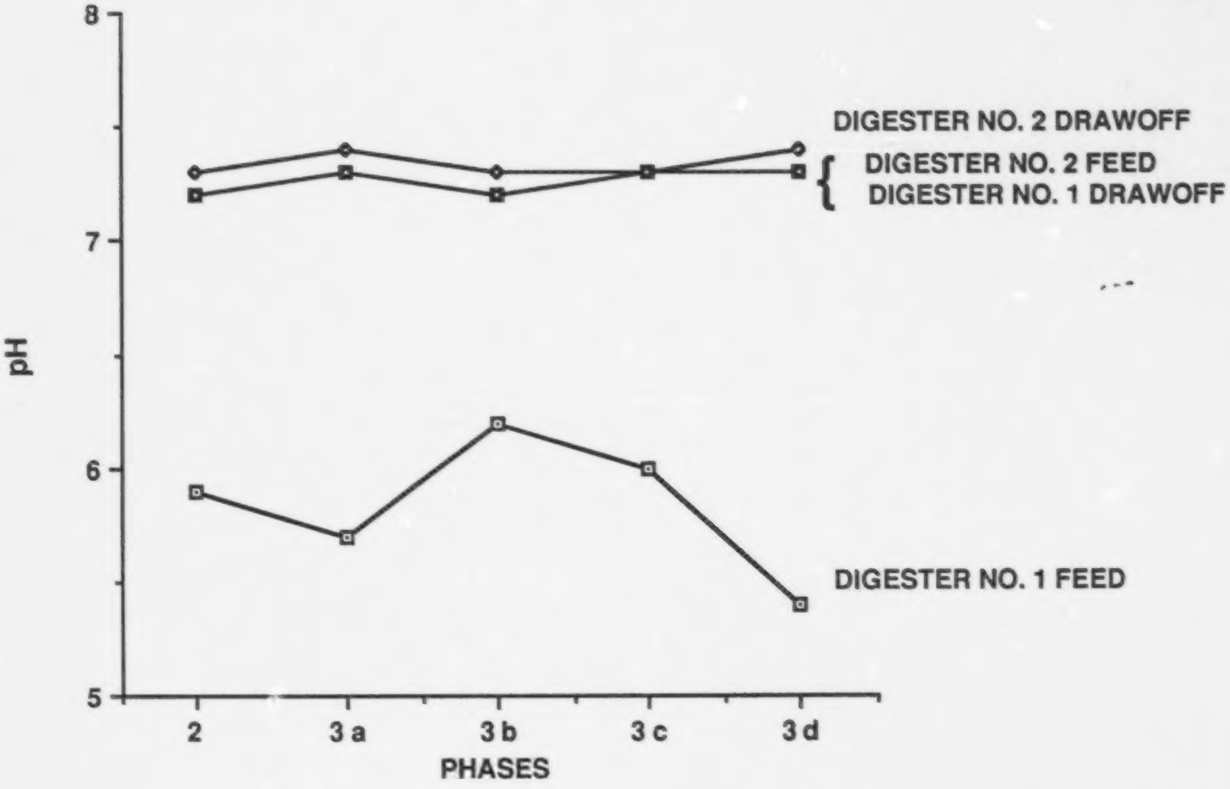


FIGURE 25 : pH OF FEED AND DRAWOFF OF CONTROL SECTION DIGESTERS

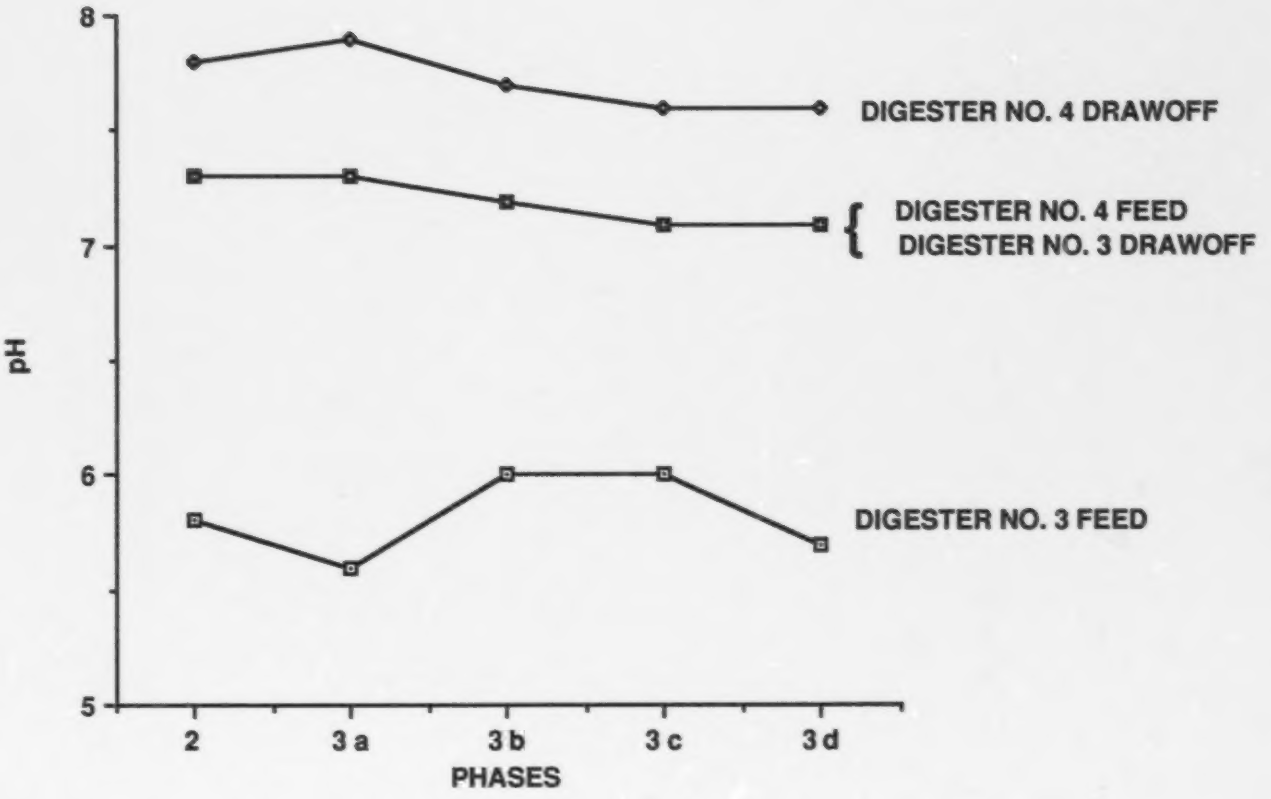


FIGURE 26 : pH OF FEED AND DRAWOFF OF EXPERIMENTAL SECTION DIGESTERS

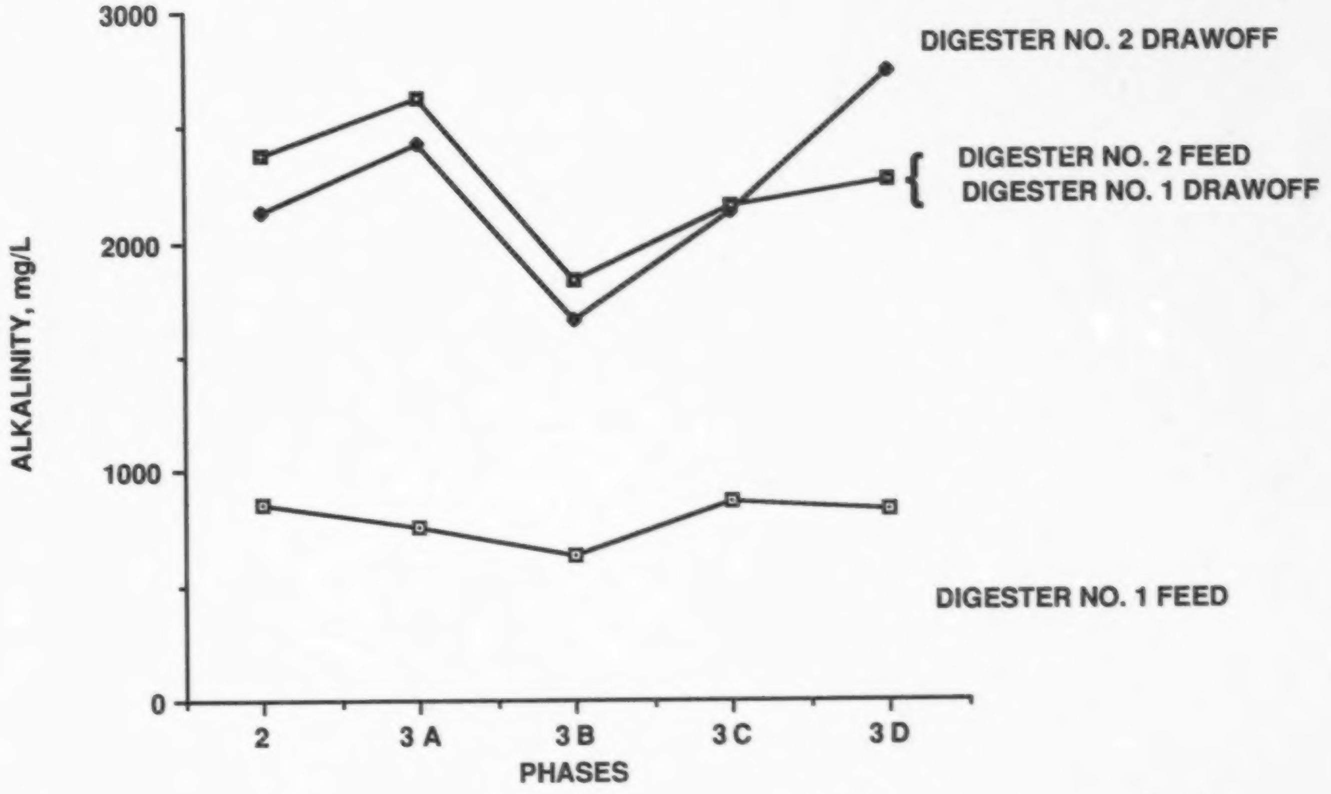


FIGURE 27 : ALKALINITY OF THE FEED AND DRAWOFF OF CONTROL SECTION DIGESTERS

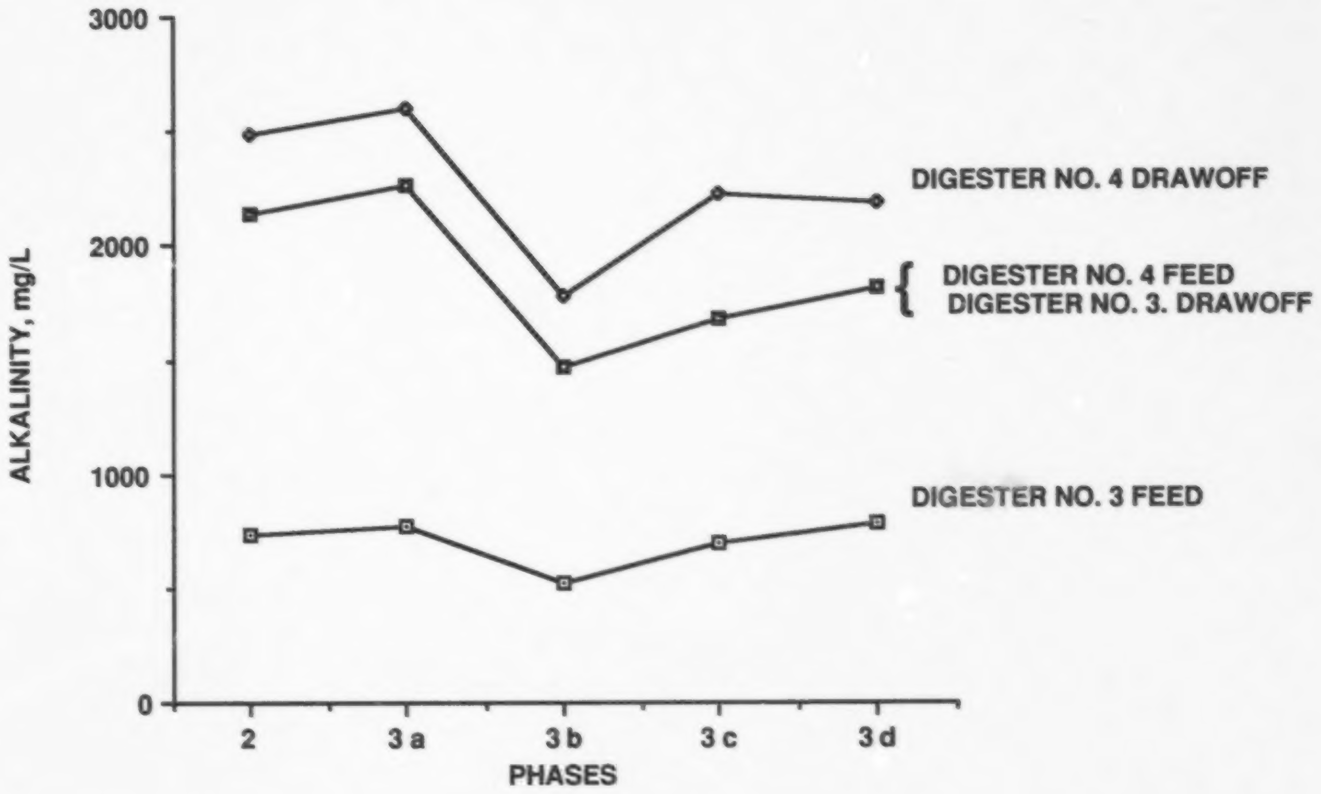


FIGURE 28 : ALKALINITY OF THE FEED AND DRAWOFF OF EXPERIMENTAL SECTION DIGESTERS

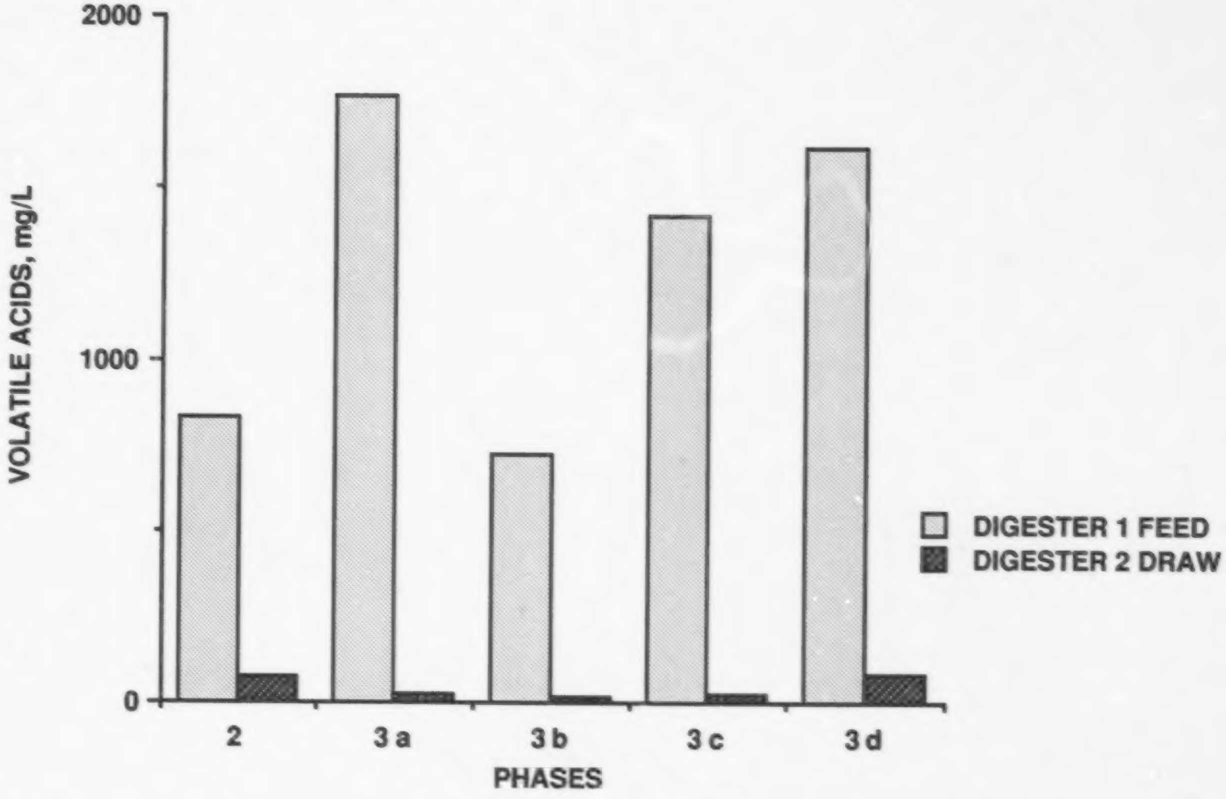


FIGURE 29 : VOLATILE ACIDS CONCENTRATION IN CONTROL SECTION DIGESTERS

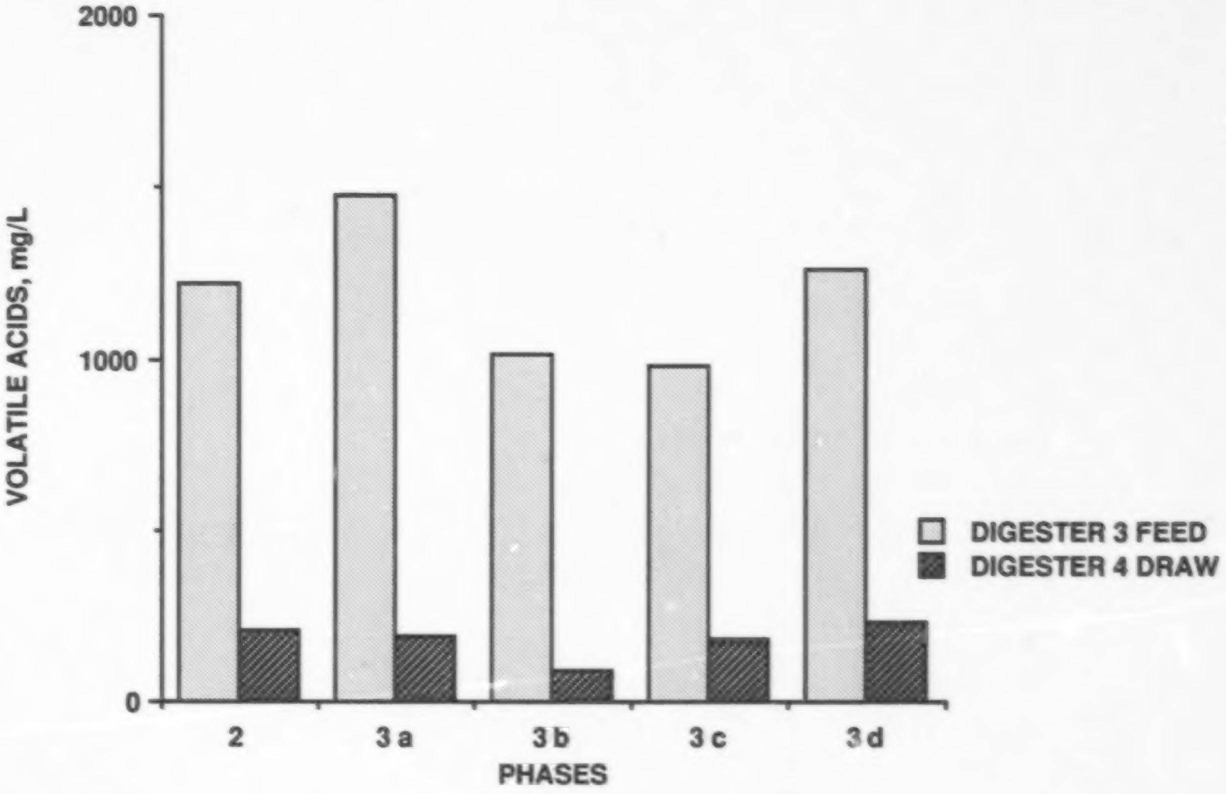


FIGURE 30 : VOLATILE ACIDS CONCENTRATION IN EXPERIMENTAL SECTION DIGESTERS

digester (Digester No. 4) and this digester performed satisfactorily along with the mesophilic digesters.

Fate of NH_4-N in Digesters--

The profile of NH_4-N in the feeds and drawoffs of the control and experimental section digesters is given in Figures 31 and 32.

The NH_4-N concentration of the digester feeds was within the range of 115 to 190 mg/L. As a consequence of the feed undergoing digestion, the drawoffs from the various digesters exhibited higher NH_4-N concentrations. These concentrations were within the range of 376 to 687 and 312 to 536 mg/L for Digester No. 2 and Digester No. 4 drawoffs, respectively. The concentration of NH_4-N did not exhibit as much of a change in Digester No. 2 during digestion and remained within a range of 422 to 655 mg/L in its drawoff. However, it increased due to thermophilic digestion in Digester No. 4 and was in the range of 432 to 717 mg/L in its drawoff. Thus the thermophilic digestion of sludge was able to convert some additional organic nitrogen into NH_4-N in Digester No. 4.

The increased concentration of NH_4-N in the thermophilic drawoff and the additional loading of NH_4-N to the aeration tanks of the experimental section caused subsequently by recycling the thermophilic drawoff to them, did not upset nitrification (See Appendix Tables E-1).

Fate of TKN in Digesters--

The TKN concentration of the digester feeds of the control and experimental sections was within the range of 1,327 to 1,903 mg/L (See Appendix Table E-1 and Figures 33 and 34). The TKN values of the drawoffs from Digesters 2 and 4 were within the range of 1,217 to 1,552 mg/L. A TKN reduction of about 2 to 20 percent was observed during digestion in the primary and secondary digesters of the control and experimental sections. During Phase 3d, the TKN values of Digester Nos. 2 and 4 drawoff sludge were found to be considerably lower than the feed TKN values. This was found to be due to dilution of the digester contents by a leakage of effluent water, which was used to lubricate the seals of the recirculating pumps of the digesters. The reduction caused by leakage was greatest for Digester 2.

Volatile Solids Destruction during Digestion--

A profile of the volatile solids destruction in the individual digesters of the control and experimental section is given in Figure 35.

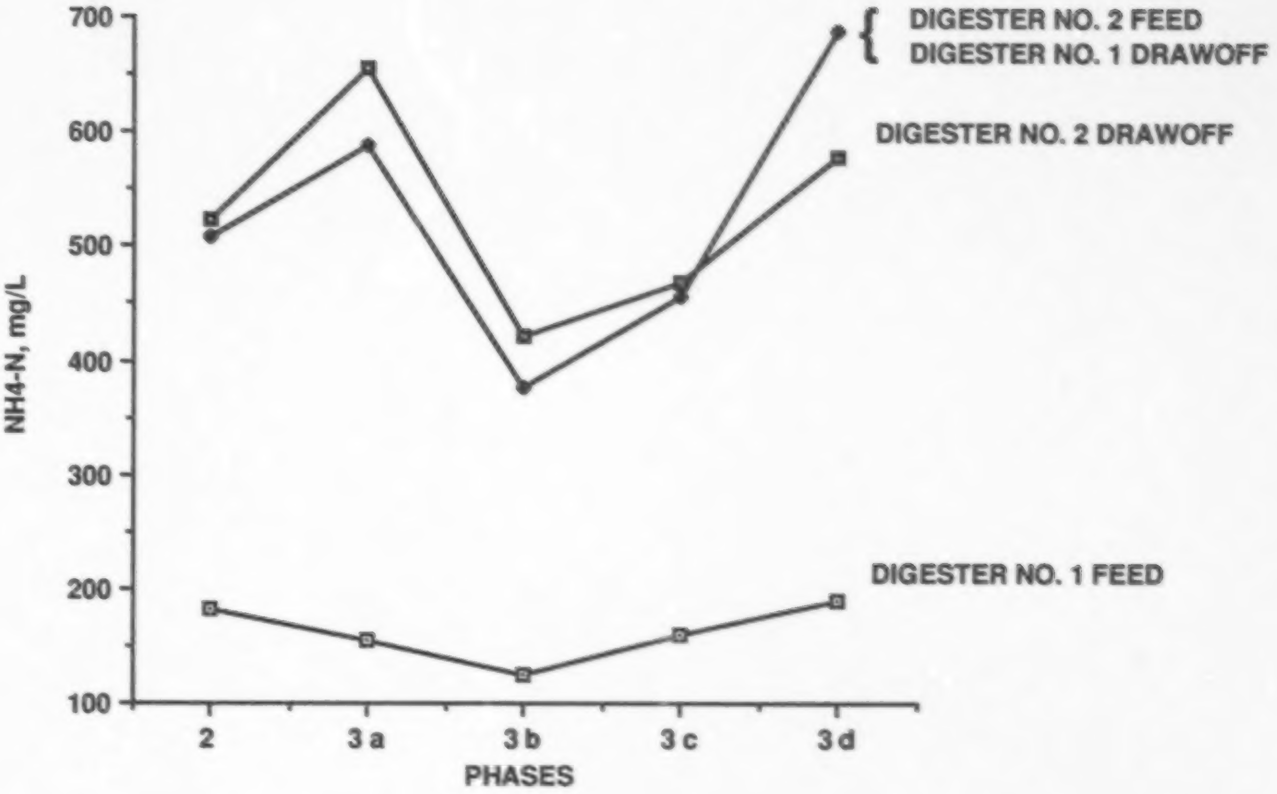


FIGURE 31 : NH4-N CONCENTRATION OF CONTROL SECTION DIGESTERS

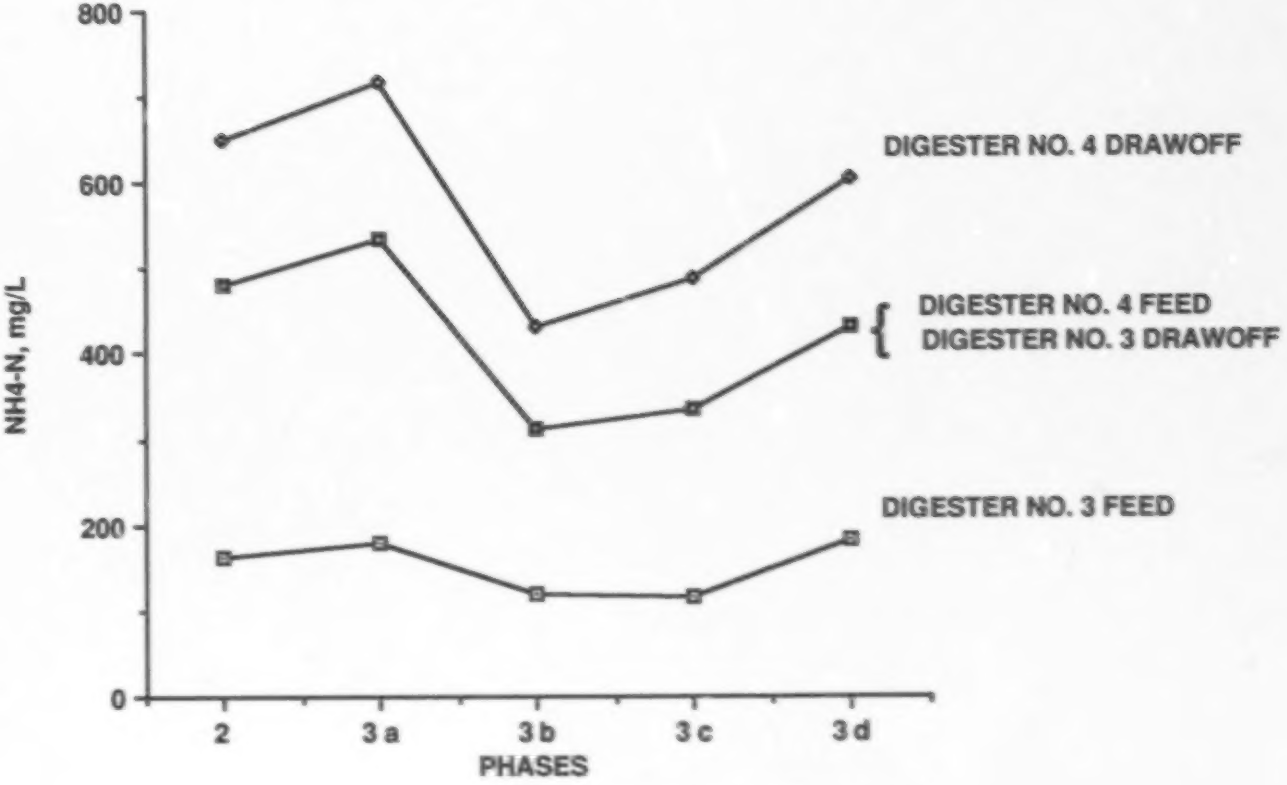


FIGURE 32 : NH4-N CONCENTRATION OF EXPERIMENTAL SECTION DIGESTERS

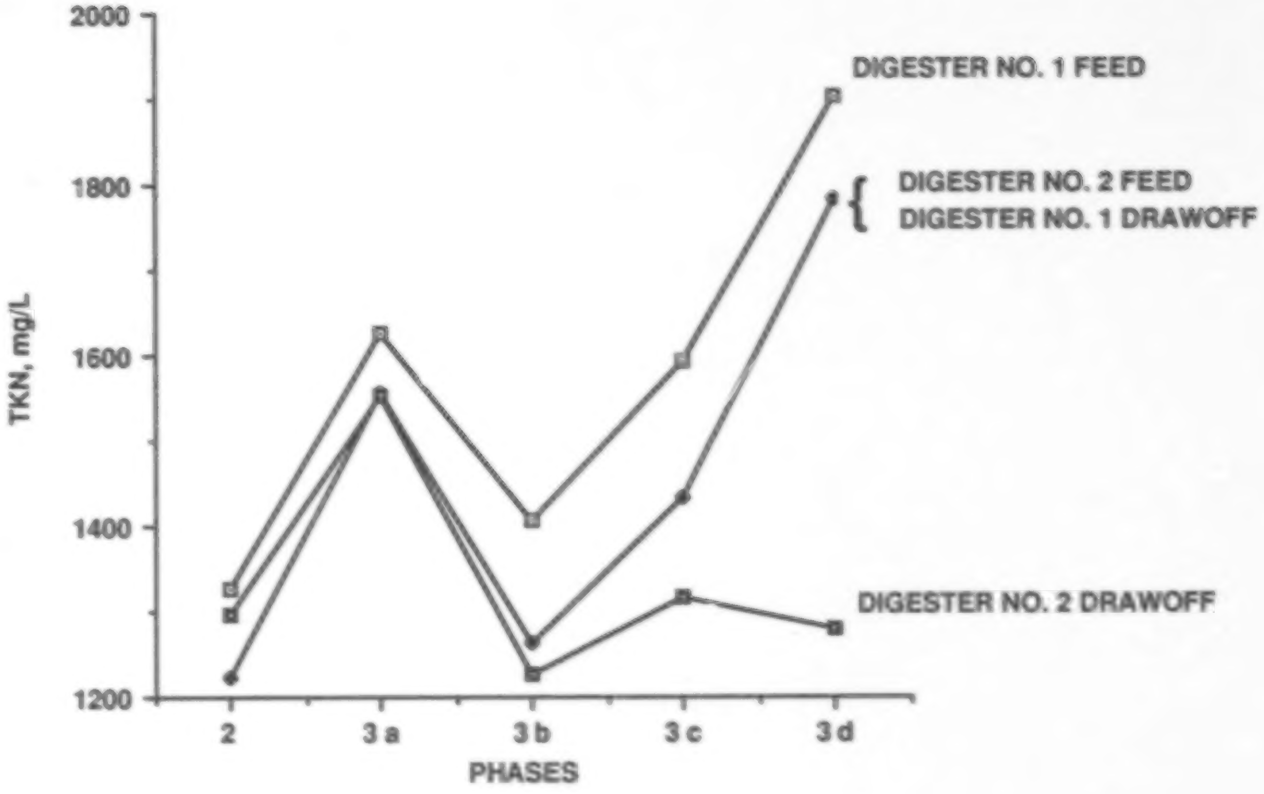


FIGURE 33 : TKN CONCENTRATION OF CONTROL SECTION DIGESTERS

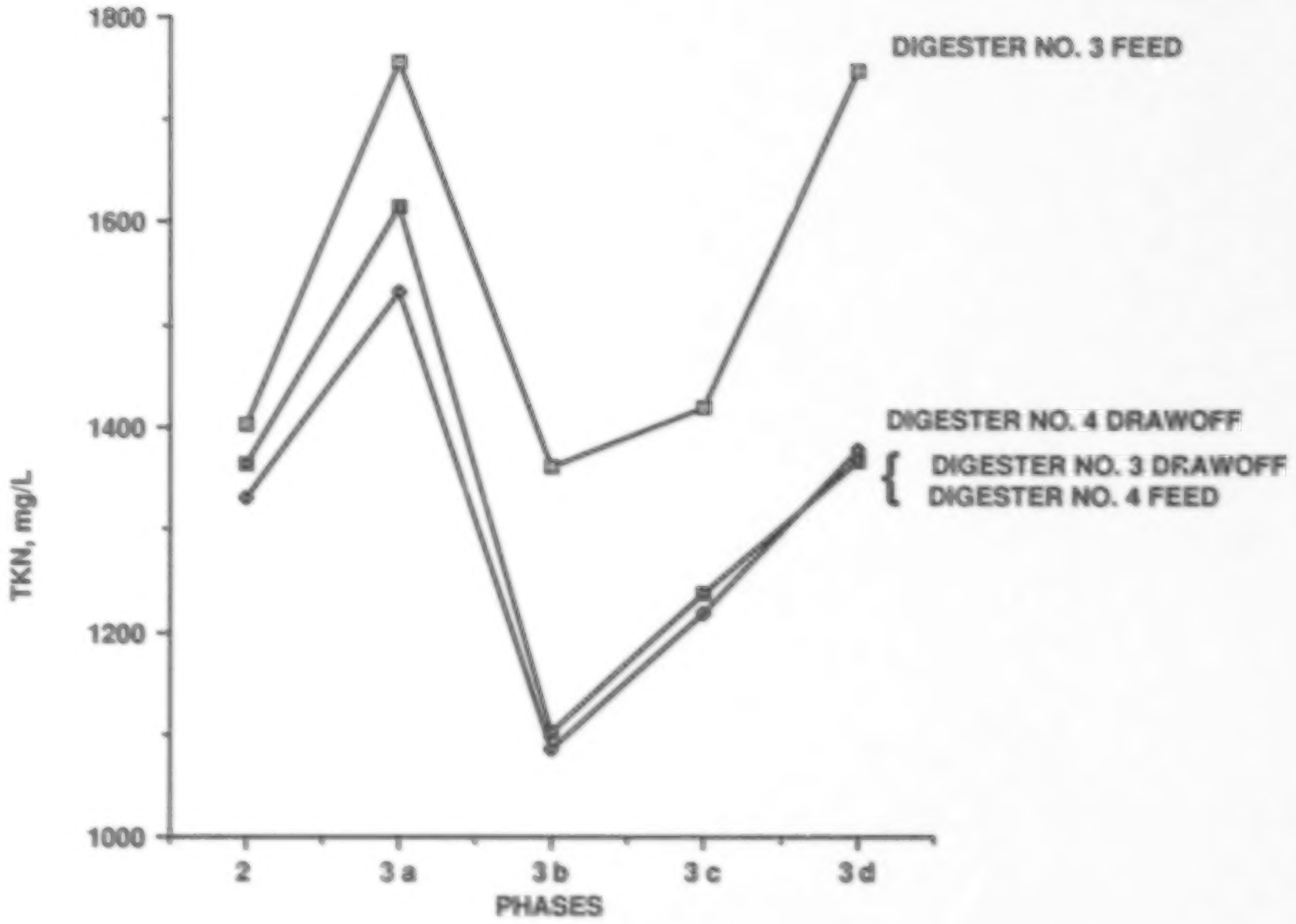


FIGURE 34 : TKN CONCENTRATION OF EXPERIMENTAL SECTION DIGESTERS

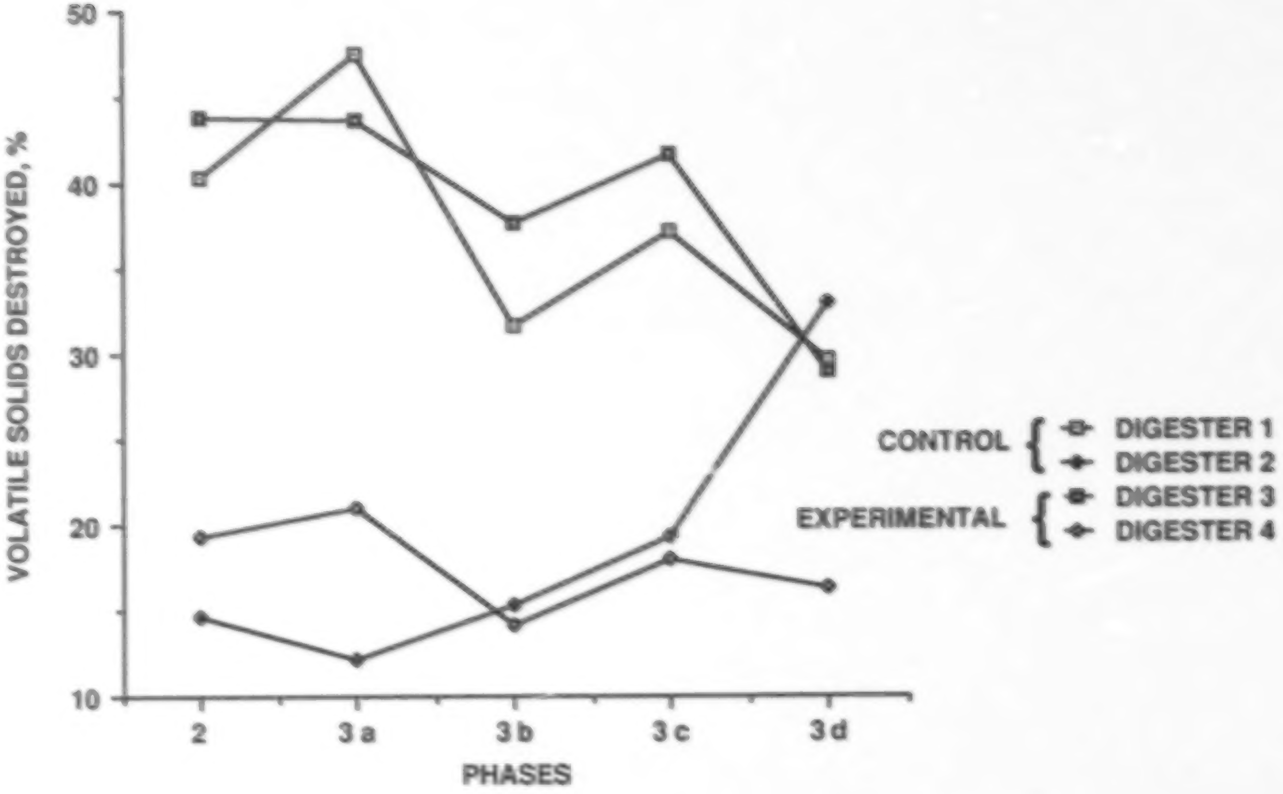


FIGURE 35 : VOLATILE SOLIDS DESTRUCTION IN DIGESTERS

While 29.0 to 47.5 percent of the volatile solids fed to the primary digesters (Digester Nos. 1 and 3), during Phases 2 through 3d were destroyed, only 12.2 to 33 percent of the volatile solids fed to the secondary digesters (Digester Nos. 2 and 4) respectively, were destroyed. The feed to the secondary digesters was the drawoff from the primary digesters. This indicates that the volatile solids fed to the secondary digesters were less biodegradable than those fed to the primary digesters.

A profile of the combined percent volatile solids destruction that occurred in the digesters of the control and experimental sections is given in Figure 36. A higher percentage of volatile solids destruction occurred in the experimental section digesters (Digester Nos. 3 and 4) than in the control section digesters (Digester Nos. 1 and 2) during Phases 2 through 3c. This was presumably due to the additional destruction of solids achieved in Digester No. 4 due to thermophilic conditions. However, the percent volatile solids destruction was lower in the experimental than in the control section digesters during Phase 3d. This was perhaps due to the shorter detention time that resulted in these digesters during this phase as a consequence of increased volumes of sludge fed per day. This was a consequence of increasing the recycling rate of thermophilic sludge drawoff to 50 percent of the amount withdrawn from Digester No. 4 into the aeration tanks of the experimental section, which was subsequently returned to the digesters.

The volatile solids destruction that occurred in the primary and secondary digesters of the control and experimental sections as a function of the volatile solids loading rate is given in Figure 37. A regression analysis of the data presented in these figures yielded the following equations for volatile solids destruction and loading rate.

Digester No. 1; $Y_m = 217.3 \; . \; X_m$, $r^2 = 0.48$
$Y_e = 7{,}663.0 \; . \; X_e$, $r^2 =$ "
Digester No. 2; $Y_m = 113.7 \; . \; X_m$, $r^2 = 0.26$
$Y_e = 4{,}011.0 \; . \; X_e$, $r^2 =$ "
Digester No. 3; $Y_m = 246.0 \; . \; X_m$, $r^2 = 0.89$
$Y_e = 8{,}693.0 \; . \; X_e$, $r^2 =$ "
Digester No. 4; $Y_m = 102.3 \; . \; X_m$, $r^2 = 0.77$
$Y_e = 3{,}617.0 \; . \; X_e$, $r^2 =$ "

where,

Y_m = VS destroyed (kg), Y_e = VS destroyed (lbs), X_m = loading rate [kg/(m^3.d)],
X_e = loading rate [lbs/(ft^3.d)], and

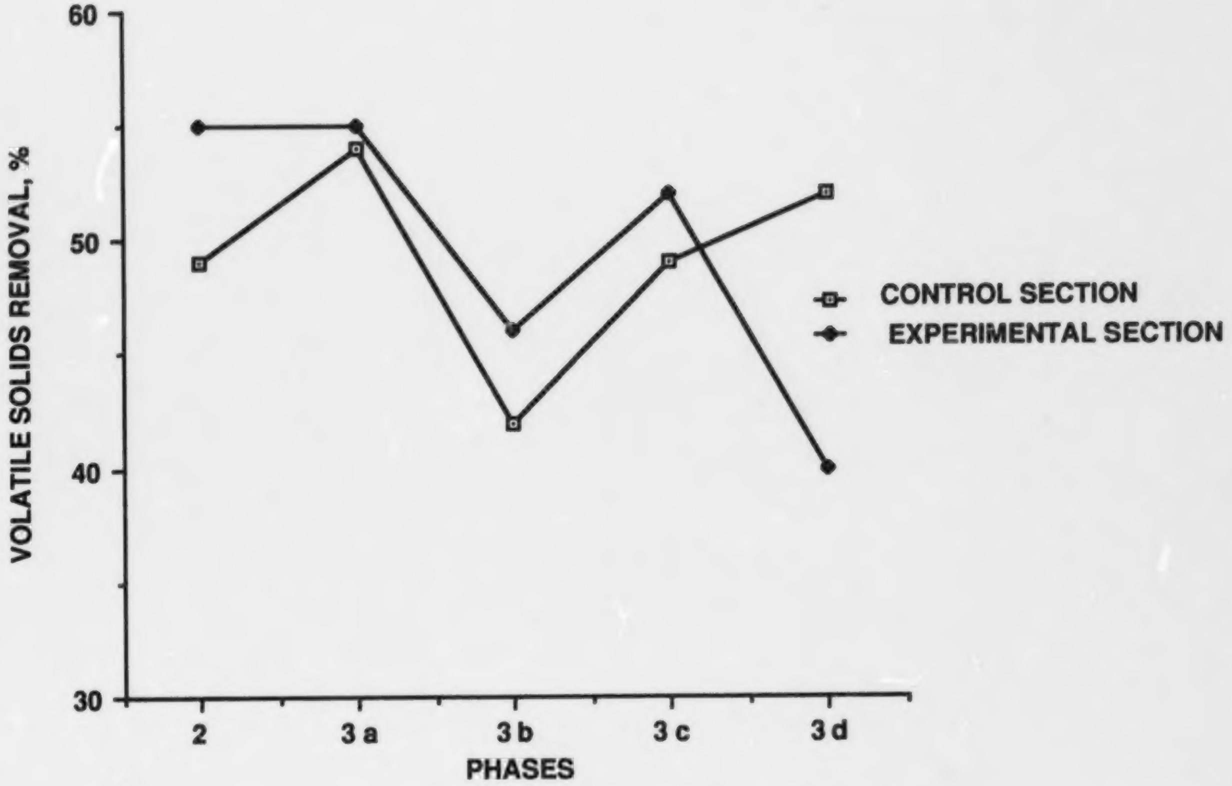


FIGURE 36 : PERCENT VOLATILE SOLIDS REMOVAL IN DIGESTERS

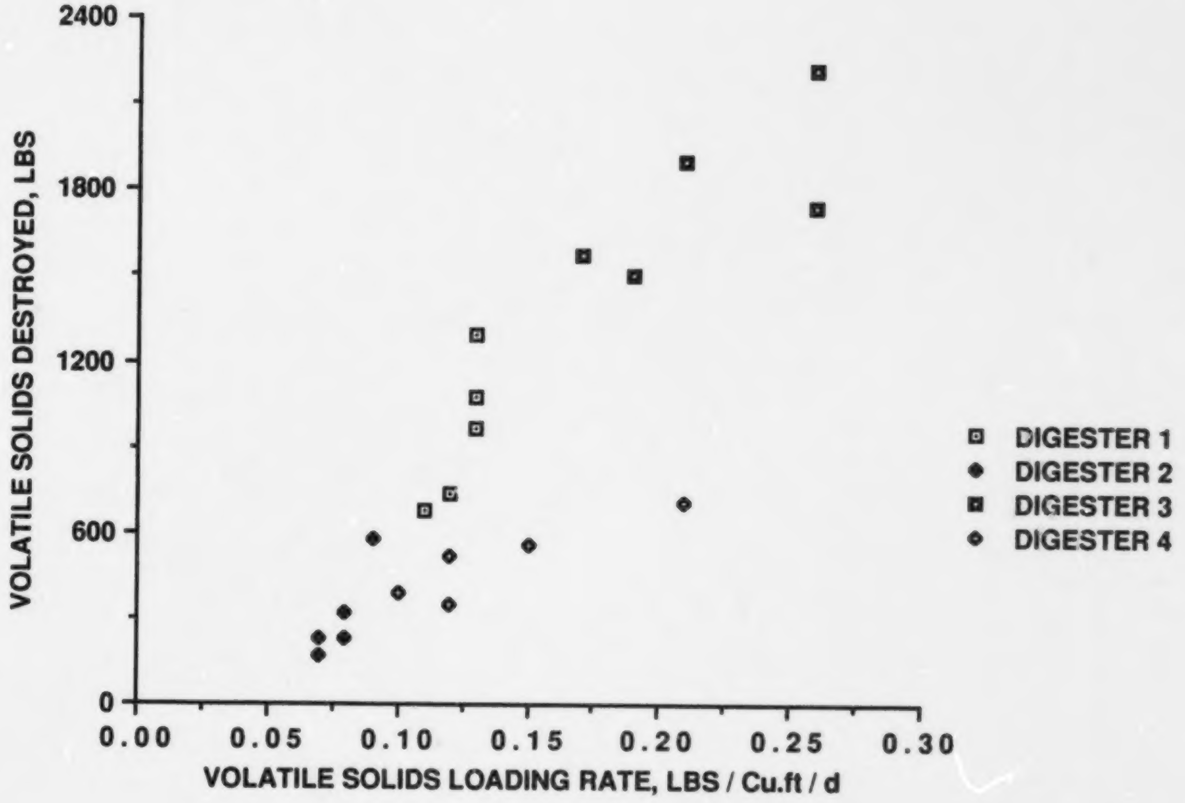


FIGURE 37 : EFFECT OF VOLATILE SOLIDS LOADING RATE ON VOLATILE SOLIDS DESTRUCTION

r^2 = square of the regression coefficient.

A comparison of the slopes of the above equations for the primary digesters (217 and 246 for Digester Nos. 1 and 3, respectively) indicate that they are similar. Likewise, the slopes of the equations derived for secondary digesters (114 and 102 for Digester Nos. 2 and 4, respectively), are also similar. However, the values of slopes for the primary and secondary digesters differed substantially (approximately 73 percent difference). Thus, the volatile solids destruction in the primary digesters is comparable, as is the case in secondary digesters, at a given loading rate. However, the extent of volatile solids destruction in the secondary digesters was significantly less than that in the primary digesters.

COD Removal in Digesters--

The profile of average total COD concentration of the feeds to the primary digesters (Digester Nos. 1 and 3) and the drawoffs from the secondary digesters (Digester Nos. 2 and 4) of the control and experimental sections digesters is given in Tables 9 and 10

A comparison of the feed and drawoff COD values of the various digesters indicate, that while a greater proportion of the COD was removed in Digester No. 1 and Digester No. 3 and only a small proportion of the COD fed to Digester Nos. 2 and 4 was removed. As discussed earlier, a similar observation was made with the volatile solids removal.

A comparison of the total COD and soluble COD of the feed to the primary digesters (Tables 9 and 10) indicate that only 3.8 to 8.3 percent of the total COD is soluble COD. This percentage decreased to 1.2 to 1.7 during digestion in the primary digesters of both the control and experimental sections. Since the percent total COD removals were in the range of 36.0 to 48.8 in the primary digesters, a significant portion of the particulate COD was solubilized in these digesters.

A comparison of the soluble COD values of the secondary digester drawoffs indicated that they were higher in Digester No. 4 drawoff than Digester No. 2 drawoff. The values for the thermophilic sludge drawoff were in the range of 528 to 944 mg/L, whereas they were in the range of 227 to 295 mg/L for the drawoff of Digester Nos. 1,2, and 3. This indicates that the thermophilic conditions in Digester No. 4 either caused some additional solubilization of particulate COD, or caused formation of soluble COD that biodegraded relatively slowly.

TABLE 9. TOTAL AND SOLUBLE COD (mg/L) OF THE FEED AND DRAWOFF OF CONTROL DIGESTERS

Digester		Phases 2	3a	3b	3c	3d
		Total COD (TCOD)				
1	Feed	33,572	40,540	36,341	38,147	44,373
	Draw	19,748	21,783	21,949	24,004	22,708
2	Feed	19,748	21,783	21,949	24,004	22,708
	Draw	16,622	18,459	18,926	19,507	15,556
		Soluble COD (SCOD)				
1	Feed	2,554	2,909	1,396	2,818	3,661
	Draw	281	363	317	380	361
	SCOD+/TCOD	7.6	7.2	3.8	7.4	8.3
2	Feed	281	363	317	380	361
	Draw	227	295	249	268	283
		TCOD Removal, %				
1		41.2	46.3	39.6	37.1	48.8
2		15.8	15.3	13.8	18.7	31.5
1-2*		50.5	54.5	47.9	48.9	64.9

+Ratio of soluble COD and Total COD, (expressed as %).

*Total COD removal through Digesters 1 and 2.

TABLE 10. TOTAL AND SOLUBLE COD (mg/L) OF THE FEED AND DRAWOFF OF CONTROL DIGESTERS

Digester		Phases				
		2	3a	3b	3c	3d
				Total COD (TCOD)		
1	Feed	33,572	40,540	36,341	38,147	44,373
	Draw	19,748	21,783	21,949	24,004	22,708
2	Feed	19,748	21,783	21,949	24,004	22,708
	Draw	16,622	18,459	18,926	19,507	15,556
				Soluble COD (SCOD)		
1	Feed	2,554	2,909	1,396	2,818	3,661
	Draw	281	363	317	380	361
	SCOD+/TCOD	7.6	7.2	3.8	7.4	8.3
2	Feed	281	363	317	380	361
	Draw	227	295	249	268	283
				TCOD Removal, %		
1		41.2	46.3	39.6	37.1	48.8
2		15.8	15.3	13.8	18.7	31.5
1-2*		50.5	54.5	47.9	48.9	64.9

+Ratio of soluble COD and Total COD, (expressed as %).
*Total COD removal through Digesters 1 and 2.

The removals of the total COD fed to the secondary digesters were for the most part in the range of 13.8 to 20.2 percent, (except Digester No. 2 during Phase 3d, where it was observed to be 31.5 percent). These removals were significantly lower than the removals observed in the primary digesters.

The overall total COD removals observed in the control digesters were for the most part in the range of 47.9 to 54.5 with the exception of the 64.9 percent removal observed in Phase 3d (Figure 38). In the experimental digesters, the percent total COD removal were comparable and were in the range of 47.6 to 56.0 percent.

The experimental section digesters removed about 2 to 5 percent more total COD than the control digesters during Phases 2 through 3b. This is presumably due to the increased digestion that occurred in the thermophilic digester of the experimental section. While the total COD removal was comparable in the control and experimental digesters in Phase 3c, the experimental digesters exhibited a lower percent COD removal than the control digesters during Phase 3d. This is presumably a consequence of a decrease in the detention time of the experimental digesters during this phase. Due to increased flow volumes of recycled thermophilic sludge drawoff into the aeration tanks, an increase in the volume of sludge fed per day to the experimental digesters resulted and this in turn caused a reduction in the detention of these digesters. Such a situation did not occur in the control section digesters and hence the COD removal was not affected.

The relationship between the volatile solids destroyed and the COD removed (kg VS destroyed/kg COD removed) during the various phases in the control and experimental digesters is given in Table 11. Similar ratios were obtained in the various phases for both sets of digesters; the ratios varied within a range of 0.41 to 0.71.

Gas Production in the Digesters of Control and Experimental Sections --

As indicated previously, problems were encountered in the measurement of gas production. This was due to leaks from the digester roof cover pressure relief vents. Many attempts were made to rectify this situation.

In this section, the gas production rates were computed by dividing the gas volume (ft^3) readings taken from the recording charts of the individual digesters by the pounds of volatile solids destroyed in them.

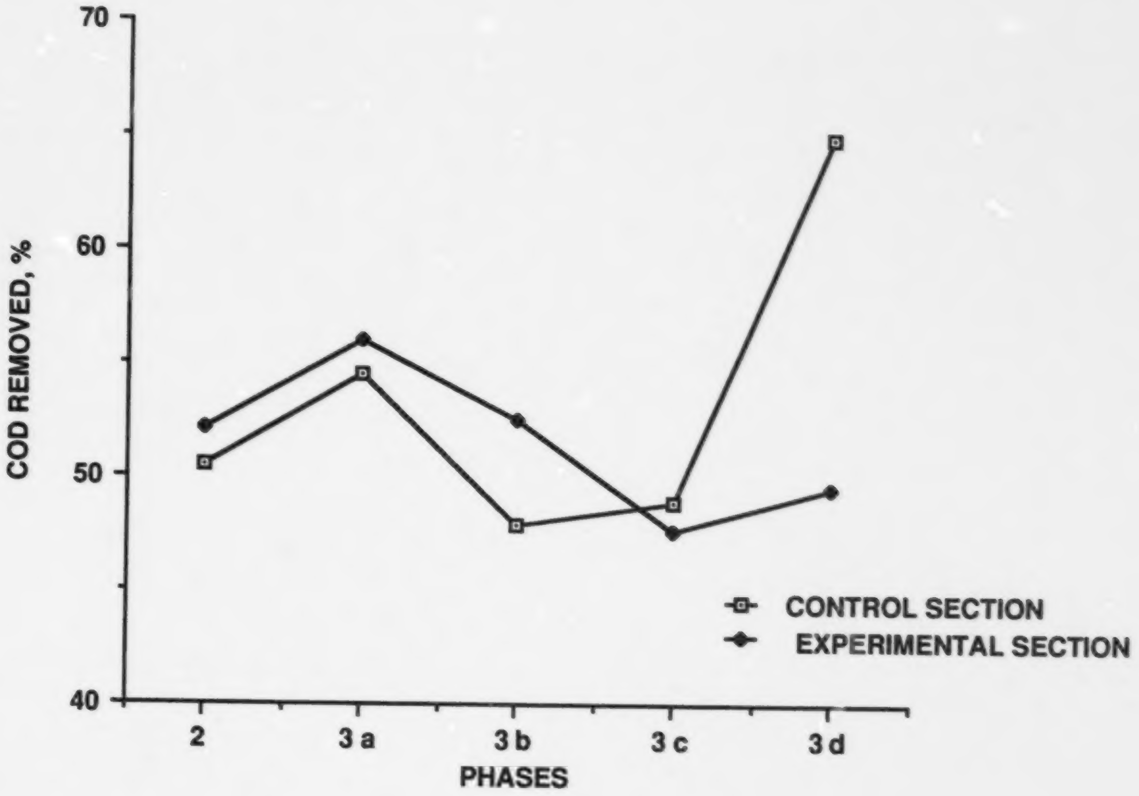


FIGURE 38 : PERCENT REMOVAL OF COD IN CONTROL AND EXPERIMENTAL SECTION DIGESTERS

TABLE 11. RELATIONSHIP BETWEEN VOLATILE SOLIDS DESTROYED AND COD REMOVED IN THE CONTROL AND EXPERIMENTAL DIGESTERS

Digesters	kg VS Destroyed/kg COD Removed Phases 2	3a	3b	3c	3d
1+2	0.60	0.61	0.50	0.62	0.41
3+4	0.68	0.61	0.50	0.71	0.48

Additionally, theoretical gas production rates were computed based on the observed COD removed (exerted) in the digesters. Theoretically, 0.351 m^3/kg (5.62 ft^3/lb) of methane would be expected for one kg of COD removed. As Hanover Park WRP digesters produce, on the average, a gas containing 62 percent of methane, the digester gas production would be at the rate of 0.566 m^3/kg (9.065 ft^3/lb) of COD removed.

From the data on COD removed and volatile solids destroyed, the theoretical or expected gas production rates for all the digesters were computed and compared to the observed gas production rates.

Table 12 presents the gas production data of the various digesters. The data indicate that the observed digester gas production rates were in the range of 0.562 to 1.161 m^3/kg (9.0 to 18.6 ft^3/lb) VS destroyed for the primary digesters, whereas they were in the range of 0.231 to 1.099 m^3/kg (3.7 to 17.6 ft^3/lb) VS destroyed in the secondary digesters.

In many instances, significant differences were noted between the expected and observed gas production rates (Table 12). In all instances, the expected gas production rates were higher than the observed values. This was perhaps due to the previously mentioned gas leaks from the digester systems. However, several extremely high expected gas production values, viz. those higher than about 1.124 m^3/kg (18 ft^3/lb) VS destroyed, were also noted. These might have resulted due to sampling and analytical errors in the measurement of COD and/or volatile solids, as these were the parameters used for obtaining the theoretical estimates of gas production. The value of 1.124 m^3/kg (18′ ft^3/lb) VS destroyed specified above, was chosen as a very liberal estimate to make this judgment, because at the digesters operating at the Stickney Water Reclamation Plant of the District, which are known to be operating without leaks, the observed gas production rates were in the range of about 0.749 and 1.124 m^3/kg (12 to 18 ft^3/lb) VS destroyed.

Profile of Heavy Metal Concentrations in Feeds and Drawoffs of Control and Experimental Section Digesters--

The concentrations of eight heavy metals were monitored during Phases 3a through 3d in the feeds and drawoffs of the experimental and control section digesters. The objective of this monitoring effort was to determine whether there was any significant difference in the distribution of the total and soluble metal concentration of the digester feeds when they are subjected to mesophilic and thermophilic digestion.

TABLE 12. QUANTITY OF GAS PRODUCED IN THE VARIOUS DIGESTERS

Digester No.		Gas Produced, m^3/kg (ft^3/lb) VS Destroyed Phases 2	3a	3b	3c	3d
1	Observed:					
	m^3/kg	0.84	0.75	0.89	0.81	1.16
	(ft^3/lb)	(13.0)	(12.1)	(14.3)	(13.0)	(18.6)
	Theoretical:					
	m^3/kg	0.93	0.89	1.22	0.89	1.76
	(ft^3/lb)	(14.9)	(14.3)	(19.7)	(14.3)	(28.3)
	% Diff:	8.8	14.8	27.2	8.7	34.4
2	Observed:					
	m^3/kg	0.46	1.09	0.59	0.39	0.23
	(ft^3/lb)	(7.4)	(17.6)	(9.6)	(6.3)	(3.7)
	Theoretical:					
	m^3/kg	0.97	1.15	0.84	0.96	0.93
	(ft^3/lb)	(15.6)	(18.5)	(13.5)	(15.4)	(14.9)
	% Diff:	42.6	5.1	29.1	59.1	75.1
3	Observed:					
	m^3/kg	0.61	0.85	0.67	0.56	0.79
	(ft^3/lb)	(9.8)	(13.7)	(10.8)	(9.0)	(12.8)
	Theoretical:					
	m^3/kg	0.84	0.93	1.08	0.77	1.34
	(ft^3/lb)	(13.5)	(14.9)	(17.3)	(12.3)	(21.4)
	% Diff:	27.5	7.8	37.6	26.9	40.1
4	Observed:					
	m^3/kg	0.44	0.83	1.08	0.78	0.67
	(ft^3/lb)	(7.2)	(13.3)	(17.4)	(12.5)	(10.8)
	Theoretical:					
	m^3/kg	0.76	0.90	1.30	0.94	0.80
	(ft^3/lb)	12.3)	14.5)	(20.9)	(15.2)	(12.9)
	% Diff:	41.2	8.1	16.7	17.9	16.6

The results of this investigation are given in Tables 13 and 14. No significant changes in the total metal concentrations were noted in the control and experimental digesters. The slight differences in the total metal concentrations of the feeds and draws, where observed, could be attributed to sampling and analytical errors.

With the exception of the soluble iron concentration, the soluble concentrations of all the other metals remained more or less the same in the digester feeds and draws.

In the case of iron, its soluble fraction in the control section primary digester feeds decreased from a range of 5.7 to 21.2 mg/L to 0.3 to 2.2 mg/L. This reduction occurred in the primary digester itself and no significant change in the soluble metal concentration occurred in the secondary digester. A similar trend was noted in the experimental section as well. The soluble iron concentrations of the primary digester No. 3 feeds, which were in the range of 8.8 to 13.8 mg/L, were reduced to values in the range of 0.02 to 0.7 mg/L. In general, neither the mesophilic nor the thermophilic digestion caused any significant solubilization of heavy metals.

LABORATORY AND PILOT-SCALE SLUDGE DEWATERABILITY STUDIES

Laboratory Studies

The objective of the laboratory studies was to obtain information on the relative polymer dosages required to condition the mesophilic and thermophilic digester sludge and the floc strength of these sludges.

A Capillary Suction Time (CST) apparatus was used to determine the optimum polymer dosage needed to condition these sludges. The lowest polymer dosage that yielded the lowest CST value on a dosage-CST curve was considered as the optimum polymer dosage. This curve was obtained under the following conditions:

1. The initial total solids concentration in the mesophilic and thermophilic sludges was 1.80 and 1.69 percent, respectively.

2. A polymer solution (Allied Colloids 763) of 0.5 percent concentration was used. Various volumes of this solution made up to 40 mL with distilled water were added to 200g portions of sludge (wet weight) placed in a 600-mL beaker.

TABLE 13. TOTAL (TOT) AND SOLUBLE (SOL) METAL CONCENTRATIONS* OF FEEDS AND DRAWOFFS OF CONTROL DIGESTERS DURING VARIOUS PHASES

Metals	Digesters Stream	PHASES 3a Tot	3a Sol	3b Tot	3b Sol	3c Tot	3c Sol	3d Tot	3d Sol
Zn	Feed 1	18.5	0.00	23.1	0.00	19.4	0.00	20.0	0.00
	Draw 1+	15.7	0.00	19.5	0.00	18.6	0.00	17.6	0.00
	Draw 2	15.0	0.00	17.6	0.00	18.0	0.00	12.4	0.00
Cd	Feed 1	0.23	0.00	0.28	0.00	0.23	0.00	0.25	0.00
	Draw 1	0.20	0.00	0.21	0.00	0.21	0.00	0.22	0.00
	Draw 2	0.20	0.00	0.20	0.00	0.27	0.00	0.18	0.00
Cu	Feed 1	43.1	0.01	44.5	0.03	35.8	0.01	34.8	0.03
	Draw 1	37.2	0.02	39.6	0.02	39.0	0.02	33.2	0.04
	Draw 2	36.1	0.02	36.4	0.09	35.7	0.01	24.2	0.03
Cr	Feed 1	3.7	0.00	4.57	0.00	2.85	0.00	4.06	0.00
	Draw 1	3.2	0.00	3.77	0.00	2.79	0.00	3.77	0.00
	Draw 2	3.1	0.00	3.41	0.00	2.90	0.00	2.64	0.00
Fe	Feed 1	226	13.6	393	5.7	239	21.2	229	16.2
	Draw 1	187	0.3	304	2.2	216	0.8	213	0.9
	Draw 2	184	0.1	267	0.3	206	0.2	152	0.2
Ni	Feed 1	4.0	0.01	3.8	0.00	2.60	0.00	2.2	0.00
	Draw 1	3.6	0.00	3.1	0.00	2.40	0.00	2.0	0.00
	Draw 2	3.5	0.00	2.9	0.00	2.43	0.00	1.43	0.00
Pb	Feed 1	6.8	0.00	5.8	0.00	4.26	0.00	5.62	0.00
	Draw 1	5.9	0.00	4.9	0.00	4.02	0.00	5.23	0.00
	Draw 2	5.5	0.00	4.5	0.00	3.89	0.00	3.56	0.00
Hg	Feed 1	2.7	0.07	3.1	0.08	2.66	0.00	2.21	0.10
	Draw 1	4.1	0.07	3.9	0.05	4.16	0.00	3.85	0.20
	Draw 2	4.4	0.003	4.1	0.05	4.49	0.00	4.07	0.00

*All values are in mg/L except Hg, which is in ug/L.
+Draw 1 is the feed for Digester No. 2.

TABLE 14. TOTAL (TOT) AND SOLUBLE (SOL) METAL CONCENTRATIONS* OF FEEDS AND DRAWOFFS OF EXPERIMENTAL DIGESTERS DURING VARIOUS PHASES

Metals	Digesters Stream	PHASES							
		3a		3b		3c		3d	
		Tot	Sol	Tot	Sol	Tot	Sol	Tot	Sol
Zn	Feed 3	19.0	0.00	21.8	0.00	18.5	0.00	36.8	0.00
	Draw 3+	16.4	0.00	17.7	0.00	17.0	0.00	19.2	0.00
	Draw 4	16.2	0.07	17.0	0.00	16.1	0.00	17.0	0.00
Cd	Feed 3	0.21	0.00	0.25	0.00	0.22	0.00	0.29	0.00
	Draw 3	0.21	0.00	0.2	0.00	0.20	0.00	0.27	0.00
	Draw 4	0.2	0.00	0.2	0.00	0.20	0.00	0.25	0.00
Cu	Feed 3	46.3	0.09	43.3	0.02	35.5	0.00	41.6	0.04
	Draw 3	46.1	0.03	35.7	0.02	34.0	0.00	34.8	0.05
	Draw 4	39.4	0.15	34.9	0.12	34.1	0.07	32.9	0.18
Cr	Feed 3	3.9	0.00	4.46	0.00	2.74	0.00	4.21	0.00
	Draw 3	3.3	0.00	3.48	0.00	2.51	0.00	3.74	0.00
	Draw 4	3.2	0.02	3.28	0.00	2.49	0.00	3.60	0.01
Fe	Feed 3	250	13.8	373	11	224	8.2	229	12
	Draw 3	211	0.02	271	0.3	198	0.2	205	0.5
	Draw 4	203	0.02	253	0.6	202	0.4	195	0.7
Ni	Feed 3	3.9	0.07	3.2	0.00	2.33	0.00	2.26	0.00
	Draw 3	3.5	0.00	2.7	0.00	2.07	0.00	1.96	0.00
	Draw 4	3.5	0.03	2.6	0.00	2.03	0.00	1.86	0.00
Pb	Feed 3	5.1	0.00	5.5	0.00	3.94	0.00	1.86	0.00
	Draw 3	6.1	0.00	4.5	0.00	3.56	0.00	5.99	0.00
	Draw 4	5.9	0.01	4.5	0.01	3.68	0.00	4.91	0.00
Hg	Feed 3	2.9	0.10	3.6	0.01	3.03	0.00	2.70	0.30
	Draw 3	4.9	0.10	4.7	0.00	4.21	0.00	4.53	0.00
	Draw 4	5.3	0.2	5.6	0.20	4.88	0.00	4.21	0.40

*All values are in mg/L except Hg, which is in ug/L.
+Draw 1 is the feed for Digester No. 2.

3. The sludge-polymer mixture was initially mixed by the gentle circulatory wrist motion until coagulation was visibly observed.

4. The coagulated sludge-polymer mixture was mixed with a laboratory stirrer for 2 min. at 500 rpm.

5. The CST of the sludge-polymer mixture, after mechanic stirring, was measured on a CST apparatus.

6. The CSTs obtained at the various polymer dosages were plotted against the polymer dosages.

Figure 39 shows the plot of CST vs. polymer dosage expressed as kg/mt dry weight of the solids contained in the wet sludge. The minimum CST values for the mesophilic and thermophilic sludges were obtained at polymer dosages of about 10 and 22.5 kg/dt (20 and 45 lbs. per short ton) of the respective sludges processed. Thus, the thermophilic sludge required a higher polymer dosage for conditioning than the mesophilic sludge.

Laboratory experiments were also conducted to determine the relative floc strengths (Vesilind, 1979) of the mesophilic and thermophilic sludges. Floc strength curves were developed by plotting the CST obtained versus the time for which a polymer-conditioned sludge sample was stirred at 1,000 rpm. Sludges which possess a high floc strength should not break down and, hence, should not yield increased CST values with increased time of stirring. In contrast, sludges with a poor floc strength will easily shear and the CST will progressively increase with increased stirring time.

The following experimental conditions were used in determining the floc strength of the mesophilic and thermophilic sludges:

1. Two hundred grams of wet sludge was placed in a 600-mL beaker.

2. Allied Colloids 763, at a concentration of 0.5 percent, was used. The dosage rate of the polymer used for conditioning the mesophilic and thermophilic sludges was 10 and 23 kg/dt (20 and 44 lbs/short ton), respectively.

3. In order to deliver the above dosage rate, 7.5 mL and 15 mL of the 0.5 percent Allied Colloids 763 polymer solution was made up to a volume of 40 mL with distilled water and then added to 200 gm portions of wet mesophilic sludge placed in two 600mL beakers.

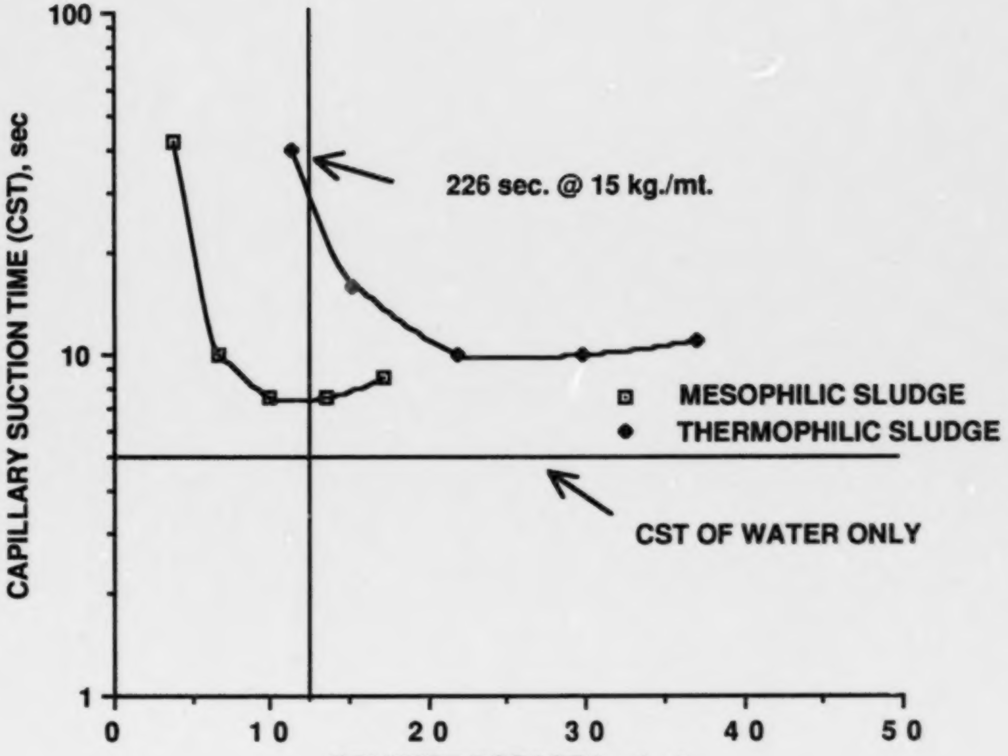


FIGURE 39 : POLYMER DOSAGE AS A FUNCTION OF CAPILLARY SUCTION TIME OF MESOPHILIC AND THERMOPHILIC SLUDGES

4. The sludge-polymer mixture was initially mixed by a gentle circulatory wrist motion until coagulation was visibly observed.

5. The coagulated sludge-polymer mixture was mixed with a laboratory stirrer for 100 secs at 1000 rpm. An aliquot from this stirred sludge-polymer mixture was taken and its CST was determined.

6. After the CST was determined, the aliquot taken from the beaker in step 5 above was added back to the beaker. The sludge-polymer mixture was stirred again for another 100 secs. (cumulative stirring time: 100 secs. in step 5 above + 100secs. instep 6 = 200 secs.) at 1,000 rpm and the CST was determined again on an aliquot taken from the sludge-polymer mixture. In a similar fashion, the CST of the sludge-polymer mixture was determined after stirring the mixture cumulatively for 300 and 400 secs.

7. The CST values obtained at the different cumulative times of stirring were plotted against the cumulative stirring times. Figure 40 represents a CST-cumulative stirring time plot. It can be observed from this figure that the thermophilic sludge had a higher floc strength than the mesophilic sludge as indicated by the lower slope of the plot for the thermophilic sludge in comparison to the plot of the mesophilic sludge. Sludges which yield plots with smaller slopes are considered to resist shear better than the sludges that yield plots with higher slopes, and hence, are considered to have a greater floc strength.

Pilot-Scale Studies--

These studies were also conducted during Phase 2. A pilot-scale Robatel continuous solid bowl centrifuge was used with mesophilic and thermophilic sludges using Allied colloids 763 as the polymer for conditioning. This centrifuge has a bowl diameter of 16 cm. It was operated at a pond depth of 2.25 cm, pond volume of 1.5L, speed of 4,4470 rpm, and G force of 1,790 cm/sec^2. Various dosages of the polymer were used and the solids concentration of the centrate and the centrifuge cake were determined after 10 minutes of operation at each of the polymer dosage rates applied. The percent capture of the solids was also determined. Three sets of data were obtained on different days for each of the two sludges (mesophilic and thermophilic).

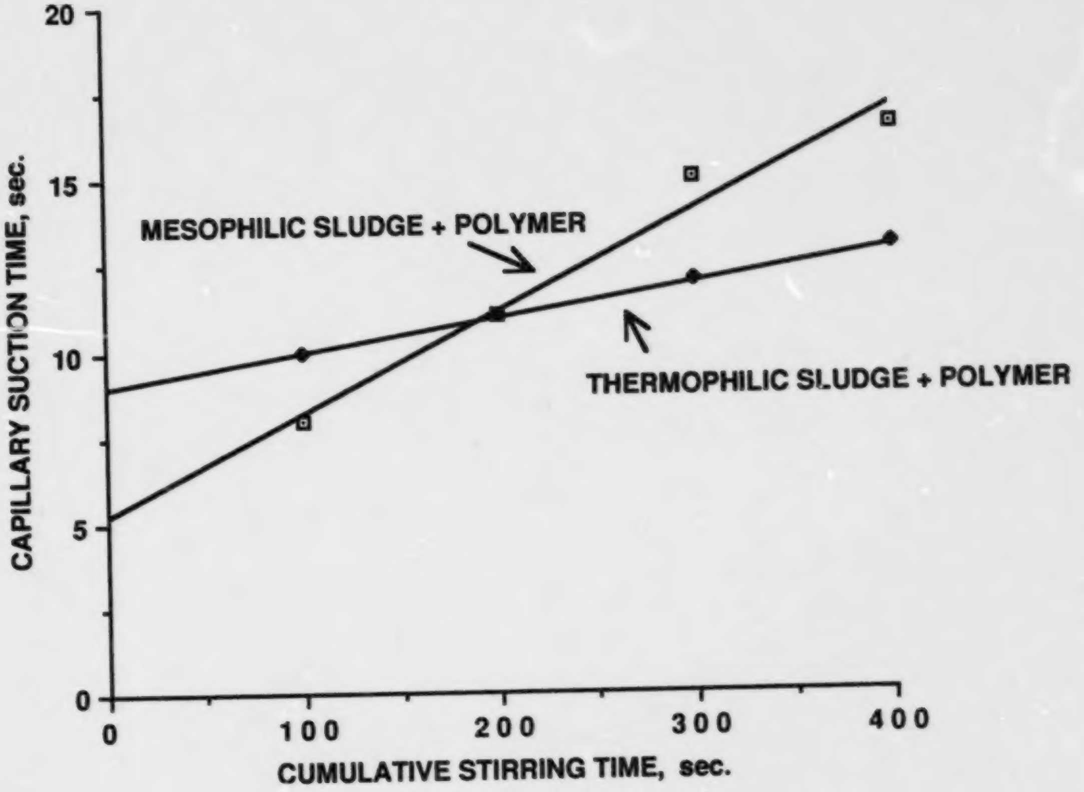


FIGURE 40 : EFFECT OF CUMULATIVE STIRRING TIME ON THE CAPILLARY SUCTION TIME OF THE SLUDGE-POLYMER MIXTURES

The concentration of the polymer solution used for conditioning the thermophilic and mesophilic sludges was 0.1 percent and 0.2 percent, respectively. Sludge was supplied to the centrifuge at a rate of 1,893 mL per min. (0.5 gpm) in all test runs.

The relationship between the polymer dosage rate and the percent solids capture and percent cake solids is presented in Figure 41 for the mesophilic and thermophilic sludge. It can be seen from this figure that a higher percentage of the solids was captured from mesophilic sludge than from the thermophilic sludge. The mesophilic sludge approached 100 percent capture as a maximum, whereas the thermophilic sludge approached 96 percent capture as a maximum. The difference in the capture rates was perhaps due to fine particles and higher pH of the thermophilic sludge then the mesophilic sludge. The centrate of the thermophilic sludge contained fine and colloidal particles that could not be captured.

It was also observed that the thermophilic sludge required more polymer to achieve a given percent solids capture than did the mesophilic sludge. Hence, for the same efficiency of dewatering, a higher polymer cost would result to condition thermophilic sludge than that required to condition mesophilic sludge. This is consistent with the CST-dosage information obtained from Figure 39.

The percent cake solids appears to be similar at any given polymer dosage for the mesophilic and thermophilic sludges as indicated in the plot between polymer dosage and percent cake solids in Figure 41.

MASS BALANCES OF VOLATILE SOLIDS AROUND VARIOUS UNIT PROCESSES

As described earlier, the mass balances of volatile solids entering and leaving some of the various unit processes were computed and the data were analyzed to delineate any significant trends.

The prime objective of studying these balances was to find whether there was any significant change in the anticipated gain in of volatile solids in the aeration basins, as a consequence of recycling the thermophilic drawoff, in addition to the volatile solids destruction that was observed in the digesters.

At the Hanover Park WRP, the volatile solids inputs to the aeration batteries mainly come through the returned sludge, which is directly returned to the aeration batteries,

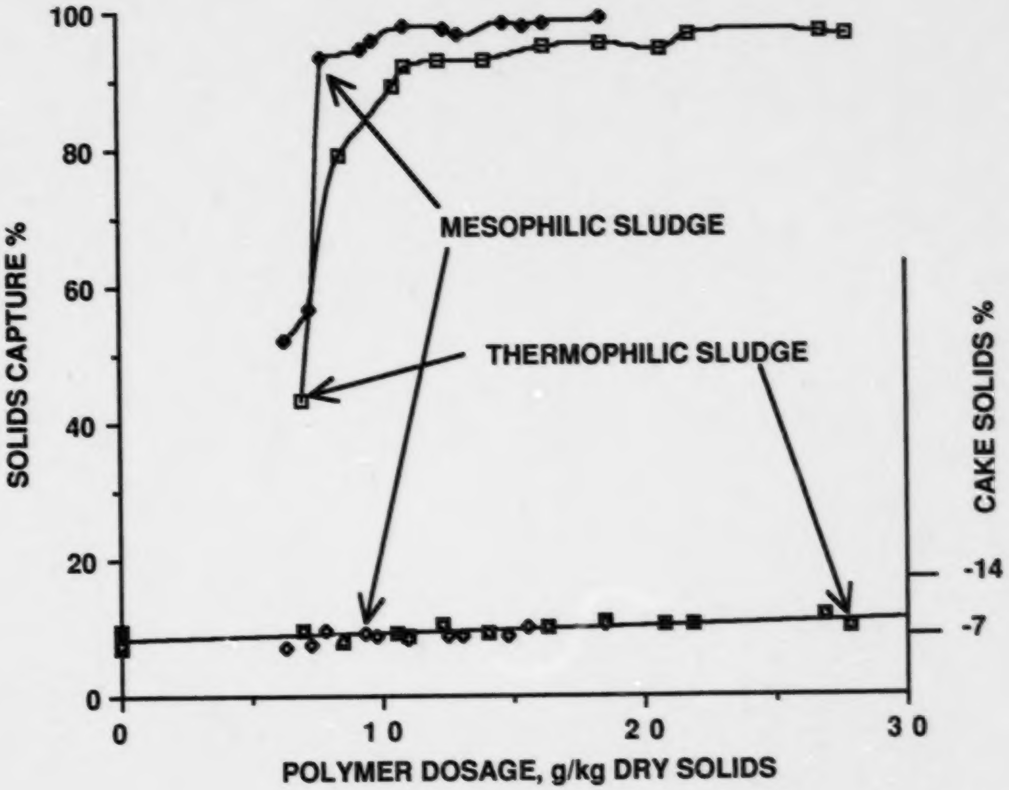


FIGURE 41 : PERCENT SOLIDS CAPTURE AND CAKE SOLIDS AT VARIOUS POLYMER DOSAGES PILOT-SCALE CENTRIFUGE STUDY

and also from the primary effluent. The volatile solids contained in the primary effluent is the sum of the volatile solids fraction of the raw sewage that could not settle and also of the fraction of the volatile solids of the waste activated sludge that could not settle.

In order to understand the movement of the volatile solids through the various flow streams around the aeration batteries, three types of mass balances are relevant to analyze for the influence by the inputs to the aeration batteries, by the performance of the aeration batteries, and by the performance of the secondary clarifiers. These balances are:

1. The aeration batteries only (Figure 3); the inputs of volatile solids to the aeration batteries are returned sludge volatile solids per day, volatile solids in recycled thermophilic sludge per day in the case of experimental section batteries, and the primary effluent volatile solids entering per day; the output from the aeration batteries is the MLVSS of the mixed liquor leaving the batteries per day.

2. The secondary clarifiers only (Figure 4); the input of volatile solids to the secondary clarifiers is the MLVSS contained in the mixed liquor leaving the aeration batteries per day.

   The output from the secondary clarifiers consists of volatile solids in effluent, waste activated sludge, and returned sludge leaving the clarifier per day.

3. The aeration batteries plus secondary clarifiers (Figure 5); the inputs of volatile solids to the aeration batteries are the same as those in (1) above; the output of volatile solids from this system is the volatile solids contained in the returned sludge, WAS, and the secondary effluent (same as the output of No. 2 above).

These various mass balances consider the accumulation of volatile solids in the aeration batteries in any given phase. The accumulation of volatile solids are insignificant in the secondary clarifiers with respect to the volatile solids contained in the aeration batteries as well as the quantity of volatile solids processed through them in the duration of any given phase. The results of the above material balances are presented below.

Mass Balance Around Aeration Batteries Only

The mass balance of volatile solids around the aeration batteries of the control and experimental sections was determined according to Equations 1 and 2. The results of the analysis are presented in Tables 15 and 16 for the control and experimental sections, respectively (see also Appendix Table G-1).

In the control section aeration batteries, the corrected difference between the VSS mass that entered the aeration batteries and the MLVSS mass that left the aeration batteries was -23.3 percent for Phase 3d. Such differences were in the range of -6.6 to -10.6 percent for the other phases. Thus there was a gain in mass across the aerator since there were more solids leaving than were entering the control section aeration batteries.

In the experimental section aeration batteries, the trend was the opposite of that in the control section aeration batteries. The corrected percent difference between the mass of VSS entering the aeration batteries and the mass of MLVSS leaving them was found to be in the range of +11.6 to +14.8 percent. There was a loss in mass across the aerator since less solids were leaving than were entering the experimental section batteries.

As noted earlier (after Equation 2), there can be a gain or loss in suspended solids across the aerator, depending on the nature of the primary effluent. Since the same primary effluent entered both control and experimental sections, either one or both of the results is in error.

Mass Balance Around Secondary Clarifiers Only

The results of the mass balance analysis of the secondary clarifiers of the control and experimental sections are given in Table 17 (See also Appendix Table G-2).

The difference in the mass of VSS entering the secondary clarifiers and the mass leaving them was in the range of 4.4 to 17.3 percent in the control section. However, in the experimental section, such differences were in the range of -12.4 to -17.5 percent. Because no VSS losses should occur across a clarifier, these differences should have averaged zero. The consistent bias in the differences observed with regard to VSS balance of the secondary clarifiers of the control and experimental sections was the opposite of the biases in the differences noted for their respective aeration batteries.

TABLE 15. MASS BALANCE OF VOLATILE SUSPENDED SOLIDS (VSS) AROUND AERATION BATTERIES A AND B OF CONTROL SECTION

Phase	Duration (Days)	MLVSS in Aeration Tanks, kgs		Accumulation Term, kgs (A_{aC})	Mass of VSS, $\times 10^6$ kg		Gain or Loss in MLVSS During Phase, 10^6 kg (G_a)	% Gain or Loss*
		At End of Phase	At Beginning of Phase		Into Aeration Tanks ++	Out of Aeration Tanks +++		
2	346	12,721	12,278	343	16.91	18.66	-1.75	-10.3
3a	122	13,360	13,501	-141	5.91	6.54	-0.63	-10.6
3b	61	11,521	11,977	-456	3.26	3.53	-0.27	- 8.3
3c	92	14.021	12,984	1,037	5.60	5.96	-0.36	- 6.6
3d	153	14,415	11,495	2,920	5.26	6.92	-1.66	-23.3

+ A_{aC} is trivial in comparison to G_a and hence ignored in the final conputation of gain or loss values.

++ Primary Effluent VSS + returned sludge VSS.

+++ MLVSS ($\times 10^6$ kg) out of Aeration Batteries A and B.

* (G_a/VSS Mass entering Aeration Tanks) x 100.

TABLE 16. MASS BALANCE OF VOLATILE SUSPENDED SOLIDS (VSS) AROUND AERATION BATTERIES C AND D OF EXPERIMENTAL SECTION

Phase	Duration (Days)	MLVSS in Aeration Tanks, kgs		Accumulation Term, kgs (A_{aC})	Mass of VSS, x10^6kg		Gain or Loss in MLVSS During Phase, 10^6kg (G_a)	% Gain or Loss*
		At End of Phase	At Beginning of Phase		Into Aeration Tanks ++	Out of Aeration Tanks +++		
2	396	17,918	16,239	1,679	27.56	24.50	3.06	11.1
3a	122	17,411	17,713	- 302	9.81	8.78	1.03	10.5
3b	61	15,350	16,599	-1,249	5.39	4.59	0.8	14.8
3c	92	17,663	16,893	770	9.23	8.16	1.07	11.6
3d	153	14,473	15,111	- 638	10.3	8.98	1.32	12.8

+ A_{aC} is trivial in comparison to G_a and hence ignored in the final computation of gain or loss values.

++ Primary Effluent VSS + returned sludge VSS.

+++ MLVSS (x10^6 kg) out of Aeration Batteries C and D.

* (G_a/VSS Mass entering Aeration Tanks) x 100.

TABLE 17. MASS BALANCE OF VOLATILE SUSPENDED SOLIDS (VSS) AROUND SECONDARY CLARIFIERS OF CONTROL AND EXPERIMENTAL SECTIONS

Section	VSS Mass (kg) Phase				
	2	3a	3b	3c	3d
Control (Secondary Clarifiers of A&B Batteries)					
Input (+)	47,129	53,624	57,888	64,873	44,588
Output (*)	43,143	49,142	54,104	61,813	36,888
% Difference	8.5	8.4	6.5	4.4	17.3
Experimental (Secondary Clarifiers of C&D Batteries)					
Input (++)	61,881	71,959	75,333	88,838	58,818
Output (**)	69,883	80,915	88,486	100,658	67,779
% Difference	-12.9	-12.4	-17.5	-13.3	-15.2

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* Mass of MLVSS coming out of aeration tanks of control section.

+ Mass of volatile suspended solids (VSS) of secondary effluent, waste activated and returned sludge coming out of secondary clarifiers of control section.

++ Mass of MLVSS coming out of aeration tanks of experimental section.

** Mass of volatile suspended solids (VSS) of secondary effluent, waste activated and returned sludge coming out of secondary clarifiers of experimental section.

NOTE: Divide values by .4536 to convert kilograms to pounds.

In view of the foregoing, it is suspected that a biased and non-representative sampling of the mixed liquor leaving the aeration batteries in both the control and experimental sections was occurring consistently, as it is the MLVSS that influence the mass balances of both the aeration batteries and the secondary clarifiers. The mass of MLVSS leaving the aeration batteries is the output of the aeration batteries and is the input to the secondary clarifiers, and is thus the common influence on their mass balances.

Mass Balance Around Aeration Batteries Plus Secondary Clarifiers

Figure 5 shows the flow of the mass of VSS around the aeration batteries and their associated clarifiers as a combined unit process. The mass balance was calculated using Equations 5 and 6. The accumulation terms were assumed to be negligible. The gain in mass G_a was calculated assuming experimental inaccuracies were negligible. The calculated gain in mass was normalized by dividing it by the total VSS input to the aerator-clarifier system for the control and experimental sections so that they could be compared with one another.

Note that the return sludge is on internal stream in the aerator-clarifier system and does not appear in the material balance. For the control section; the VSS input is the VSS in the primary effluent; for the experimental section, the VSS input is the sum of the VSS input in the primary effluent and the VSS in the recirculated digested sludge. The VSS data used to calculate these values are presented in Appendix Table G-3.

The relative gain in mass (kg VSS generated/by VSS input) is presented in Table 18 based on primary effluent VSS only for the control section and based on two bases for the experimental section: primary effluent VSS only and on primary effluent VSS plus recirculated digested sludge VSS. The quantities of VSS generated appear to be reasonable values although perhaps somewhat high for the control system. The quantities for the experimental system show no trends developing as recycle rate increases from Phase 2 to Phase 3d. However, unless the trends were large they would be obscured by scatter in the data.

The relative mass of VSS generated would be more amenable to interpretation if it were based on soluble COD or BOD because the bulk of the nutrients for growth of activated sludge comes from this source. Future studies should include these measurements.

TABLE 18. RELATIVE GAIN IN VOLATILE SUSPENDED SOLIDS MASS* IN CONTROL AND EXPERIMENTAL SECTIONS AERATION PLUS SECONDARY CLARIFIER SYSTEMS

	Control Section	Experimental Section	
Phase	$\frac{\text{Kg VSS}_{gen}}{\text{Kg VSS}_{pe}}$	$\frac{\text{Kg VSS}}{\text{Kg VSS}_{pe}}$	$\frac{\text{VSS}_{gen}}{\text{VSS}_{pe} + \text{VSS}_{dd}}$
2	0.58	0.28	0.28
3a	1.18	0.47	0.52
3b	0.82	0.07	0.09
3c	1.50	0.17	0.26
3d	1.37	0.24	0.40

---

* $\frac{\text{Kg VSS Generated}}{\text{KG VSS}_{pe}}$ $[(\text{Kg VSS}_{se} + \text{Kg VSS}_{WAS}) - \text{KG VSS}_{pe}]$.
Subcripts = gen: generated; pe: primary effluent; se: secondary effluent; dd: digester draw; WAS: Waste Activated Sludge.

Mass Balance of Volatile Suspended Solids around the Primary Settling Tanks

As indicated in the "Materials and Methods" section the input of volatile solids to the primary clarifiers was from raw sewage and WAS streams entering them. The solids that settle in the primary clarifiers of the control and experimental sections comprise the feed to the primary digesters of these respective sections.

There are two ways of estimating the feed input to the digesters; one involves the direct measurement of the volatile suspended solids contained in the bottom drawoff of the primary clarifiers and the other involves a computation. This computation involves multiplying the difference between the volatile suspended solids content of raw sewage and primary effluent with the flow of raw sewage processed. The volume of WAS that enters the clarifier can be ignored in this computation as it was a tiny fraction of the raw sewage flow.

As mentioned previously, the flow volumes used for the digester feed and drawoff are derived from the cover height increases of the primary and secondary digesters, respectively. It is notable that flows based on these measurements were found to be precise, and were comparable to the flow volumes estimated from either the digester feed pump strokes or the depth of the sludge miniscus in the sludge holding basins in numerous instances. However, as these two latter measurements were more prone to gross errors in flow measurement as evidenced on several occasions, flow volumes derived from cover height increase were employed in the computation of mass balances.

A comparison of the mass balance results derived as above is presented in Table 19 (See also Appendix Table G-4). From this table it can be seen that there was a substantial difference between the mass of control section digester feed volatile solids, which were directly measured, and those that were computed as mentioned above. The percent difference values varied within the range of 8.9 to 95.8. The same comparison for the feed of the primary digester of the experimental section (Digester No. 3) indicated that the difference between the directly measured values and computed values were within the range of -12.4 to -2.7 percent, which is a considerably narrower range than that observed for the feed volatile solids of the control section primary digester (Digester No. 1).

In view of the above differences, the mass loadings to the digesters and the mass of volatile solids discharged via the drawoffs were derived by using the directly measured

TABLE 19. COMPARISON OF MASS BALANCES ON VOLATILE SOLIDS INPUT TO DIGESTERS NOS. 1 AND 3

	Digester #1 (Control Section) (Mass of Feed Volatile Solids (kg)			Digester #3 (Experimental Section) Mass of Feed Volatile Solids (kg)		
Phase	Direct Measurement +	By Computation *	Percent Difference	Direct Measurement +	By Computation *	Percent Difference
2	1,214	1,323	8.9	1,629	1,427	-12.4
3a	1,234	1,618	31.2	1,979	1,872	-5.4
3b	972	1,902	95.8	1,809	1,906	-5.3
3c	1,182	2,282	93.1	2,421	2,356	-2.7
3d	1,129	1,566	38.7	2,733	2,546	-6.8

+ Digester Feed VS concentration x Flow (both measurements were made).

* kg VS = $Q_{inf} (X_{inf} - X_{pe}) + Q_{was} X_{was}$
Where Q_{inf} and Q_{was} are flows of raw sewage and waste activated sludge, and X_{inf}, X_{pe}, and X_{was} are volatile solids in raw sewage, primary effluent, and waste activated sludge, respectively.

NOTE: Divide values by .4536 to convert kilograms to pounds.

values of volatile solids concentration in the feeds and drawoffs of the digesters. This was done for consistency with the general position (adhered to throughout this study) that direct measurements be used rather than calculated values, whenever possible.

Mass Balance Around the Primary and Secondary Digesters

The streams containing total volatile solids entering the primary digesters and leaving the secondary digesters, are given in Figure 7.

The mass balance analysis was made on the control and experimental sections digesters according to Equations 8 and 9 except accumulation was determined in an approximate fashion. Appropriate correction factors were computed using Phase 2 conditions as the reference values.

As an example, the computation of the correction factors needed to adjust the volatile solids data collected during Phases 3a and 3b utilizing Phase 2 conditions as the reference values and for obtaining the corrected percent volatile solids destruction in the experimental digesters is given in Appendix Table H-1.

A summary of the mass balance of volatile solids around the control and experimental digesters, which was obtained from the above computations, is presented in Table 20 (See also Appendix Table G-5).

A comparison of the percent VS destroyed in the control section with the percent VS destroyed in the experimental section of the Hanover Park WRP, is made and the observed differences in the percent VS destroyed, between the experimental and the control sections for the various phases are plotted in Figure 42. It can be seen from this figure that about 2 to 5 percent of higher volatile solids destruction occurred in the experimental section than in the control section in Phases 2 through 3c. When the recycling of the thermophilic drawoff was increased to about 50 percent in Phase 3d the volatile solids destruction was 12.5 percent lower than that of the control section. This was presumably due to the lower detention time of digesters 3 and 4 than in the previous equilibrium phases. The detention time of these digesters averaged 4.4 days during Phase 3d in comparison to the 5.3 to 8.2 days of detention time observed during Phases 2 through 3c. In contrast to these detention times, the detention times of the control section digesters were in the range of 9.7 to 11.8 days.

TABLE 20. MASS BALANCE OF VOLATILE SOLIDS AROUND PRIMARY AND SECONDARY DIGESTERS

Phase	VS (In) kgs (lbs)	VS (Out) kgs (lbs)	Corrected VS (Out) kgs	% VS Destroyed	
				Corrected	Uncorrected
	Control Digester System (Digesters 1 and 2)				
2	483,678 (1,064,092)	245,700 (540,540)	245,700 (540,540)	49.2	49.2
3a	150,836 (331,840)	69,485 (152,866)	70,734 (155,615)	53.1	53.9
3b	59,392 (130,662)	34,354 (75,579)	35,241 (77,531)	40.7	42.2
3c	108,936 (239,660)	55,284 (121,624)	56,413 (124,109)	49.2	48.2
3d	173,099 (380,817)	81,716 (179,775)	81,446 (179,181)	52.9	52.9
	Experimental Digester System (Digesters 3 and 4)				
2	646,560 (1,422,432)	293,580 (645,876)	293,580 (645,876)	54.6	54.6
3a	241,893 (532,164)	107,813 (237,188)	109,062 (239,936)	54.9	55.4
3b	110,576 (243,268)	59,198 (130,235)	58,234 (128,115)	47.3	46.5
3c	223,183 (491,004)	106,845 (235,060)	106,837 (235,042)	52.1	52.1
3d	419,011 (921,825)	248,625 (546,975)	249,800 (549,650)	40.4	40.7

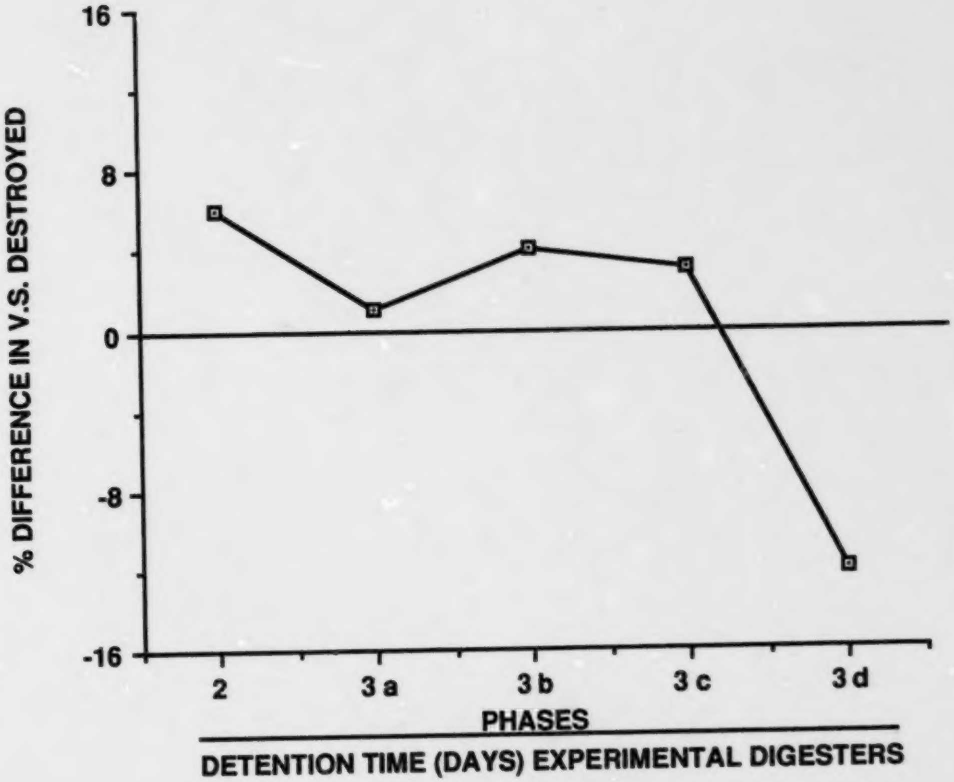

FIGURE 42 : DIFFERENCE (%) IN V.S. REDUCTION BETWEEN EXPERIMENTAL AND CONTROL DIGESTERS

Volume Balance of the Thermophilic Sludge Recycled

In order to assess the effect of recycling Digester No.4 drawoff to the aeration batteries of the experimental section, on the volume of the sludge withdrawn in each of the successive phases of the experimental section, a comparison was made of the volume recycled to the aerator with the increase in sludge volume processed through Digester Nos. 3 and 4, was made.

Table 21 compares the incremental increase in flow from Digester 4 that occurred with each increase in recycle flow during the progression of the experiment through Phases 2 to 3d. The table shows that the step increases in recycle were very nearly matched by increases in volumetric flow through the digesters of the experimental section. Thus, for example, recycling 50 percent of the digested sludge to the aerator would cause the absolute quantity of digested sludge leaving the digester to increase by almost the same percentage, causing a proportionate decrease in retention time in the digester.

OVERALL LOSS OF VOLATILE SOLIDS IN THE CONTROL AND EXPERIMENTAL SECTIONS

From the results of the various mass balances, which are presented above, the following conclusions may be drawn:

- There was insignificant reduction in the volatile solids due to thermophilic drawoff recycling into the aeration batteries.

- Volatile solids destruction was two to five percent higher in the experimental section digesters than in the control section digesters. The detention time of the experimental section digesters was within the range of 5.3 to 8.2 days. However, when the detention time was dropped to 4.4 days the volatile destruction in these digesters was 12.5 percent lower than the control section digesters. The higher volatile destruction observed in the experimental section digesters was attributed exclusively to the thermophilic conditions of the secondary digester of the digester system.

- As there was an insignificant reduction of volatile solids in the aeration tanks of the control and experimental Sections, and the observed higher volatile solids reduction in the experimental section digesters was attributed to the thermophilic digestion, it is concluded that the recycling of thermophilic drawoff into the aeration tanks is nonfunctional in achieving any additional volatile solids destruction.

TABLE 21. COMPARISON OF INCREMENTAL INCREASES IN THERMOPHILIC SLUDGE RECYCLE FLOW AND THERMOPHILIC SLUDGE DRAWOFF

Phase	Recycled Thermophilic Sludge Volume, Cu. m/d		Digester No. 4 Drawoff, Cu. m/d	
	Total+	Increase	Total++	Increase
2	0.0	-	72.3	-
3a	10.5	10.5	79.9	7.6
3b	28.7	18.2	101.5	21.6
3c	45.3	16.6	112.4	10.9
3d	72.2	26.9	133.2	20.8

+Volume as measured by pump flow rate x time.
++Volume as measured by change in cover height of Digester No. 4.

- The volume of the thermophilic digester drawoff, which is recycled to the aeration tanks, has returned in total as the input to the primary digester of the experimental section, thereby causing a significant reduction in its detention time.

MASS OF VOLATILE SOLIDS ULTIMATELY DISPOSED OF ON THE HANOVER PARK WRP FARM

Data were collected on the mass of volatile solids disposed on the Hanover Park WRP farm from the control and experimental sections in each phase. These data were computed as g (lbs) of volatile solids disposed of on the farm per m^3 (million gallons) of sewage processed in each of these sections. A plot of these data is presented in Figure 43.

From Figure 43, it can be seen that the mass of volatile solids disposed on the farm, g/m^3, (lbs per million gallons) of sewage processed is quite comparable during Phases 2 to 3b for the control and experimental sections. During Phase 3c, the volatile solids disposed of on the farm from the experimental section, was lower by about 4.55 g/m^3 (38 lbs/mil. gal.) of sewage processed than the control section. However, during Phase 3d a slightly higher mass of volatile solids per m^3 of sewage processed was disposed of on the farm from the experimental section than from the control section (45.3 g/m^3 vs 41.8 g/m^3; 378 lbs vs 349 lbs per mil. gal.).

The data show good consistency and allow a determination of the statistical significance of the differences in sludge mass produced for the phases where recycling rate was high. Table 22 shows the mean sludge production (lbs/mil. gal.) for the control and experimental section during Phases 2, 3a, 3b and 3c, and shows the calculation of the mean, standard deviation, and "t" statistics for the difference based on results obtained during these phases.

The table values of the "t" statistic for two tailed and one tailed tests are as follows:

One Tailed		Two Tailed	
α = .05	t = 2.35	α = .05	t = 3.18
α = .01	t = 4.54	α = .01	t = 5.84
DF = 3		DF = 3	

The above shows that there is no significant difference in sludge production between the control and experimental sections in these four phases. Because of the loss of information content when performing such a comparison with mean

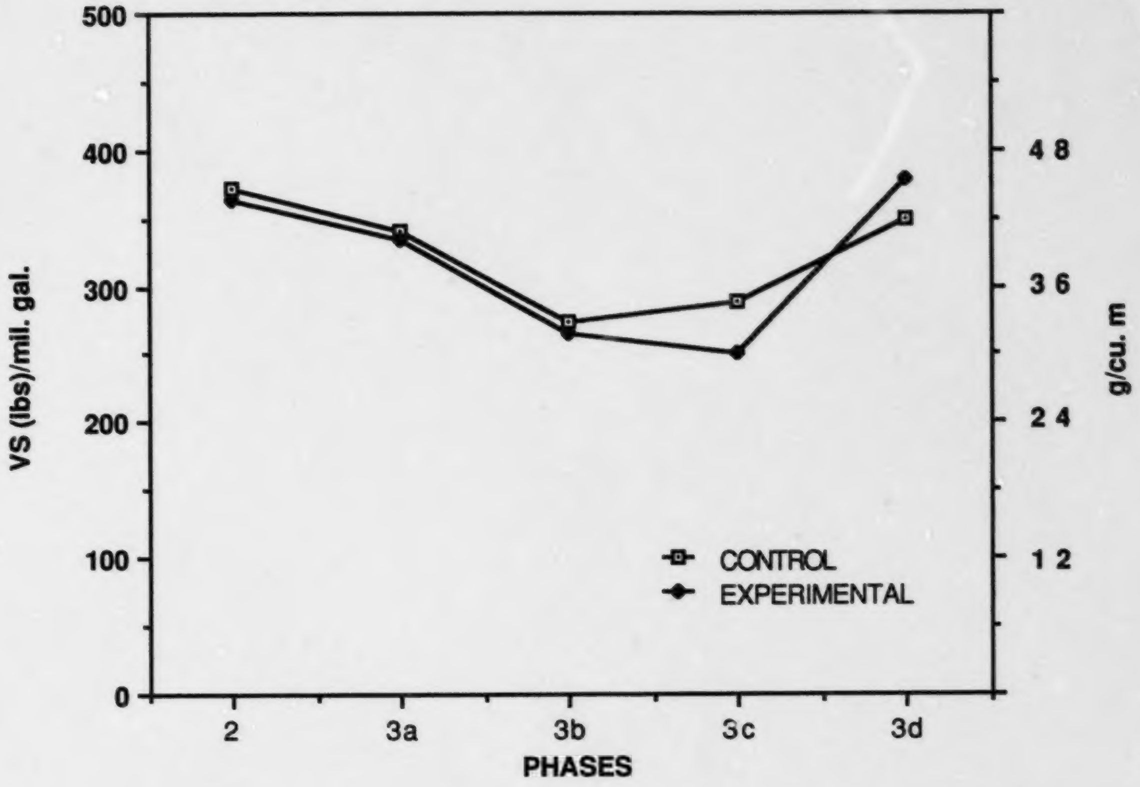

FIGURE 43 : VOLATILE SOLIDS DISPOSED ON FARM

TABLE 22. AVERAGE SLUDGE PRODUCTION AND RELATED STATISTICS OF THE CONTROL AND EXPERIMENTAL SECTIONS DURING VARIOUS PHASES

Phase	Lbs. VS/mil. gal Experimental	Lbs. VS/mil. gal Control	Difference
2	364	372	- 8
3a	334	340	- 6
3b	265	274	- 9
3c	250	288	-38

Avg Difference = 15.25 SD = 15.22

$|t| = \frac{(15.25)}{(15.22)}\sqrt{4} = 2.00$ DF = 3 values, a similar comparison was made for the sludge production of control and experimental sections using the daily values of sludge production (lbs/mil. gal.) during Phase 3c. During this phase an apparently lower average sludge production was noted for the experimental section than the control section during Phases 2, 3a and 3b.

The mean, standard deviation, and "t" statistic for the difference in sections based on daily results during Phase 3c are as shown:

Avg Difference = -36.25
SD = 221.49
$|t| = 1.47$
DF = 80

The table values of the "t" statistic for two tailed and one tailed tests are as follows:

One Tailed		Two Tailed	
$\alpha = .05$	$t = 1.66$	$\alpha = .05$	$t = 1.99$
$\alpha = .01$	$t = 2.37$	$\alpha = .01$	$t = 2.63$
DF = 80		DF = 80	

As the computed "t" value is lower than the tabulated "t" values it can be concluded that there is no significant difference in sludge production between the control and experimental sections in Phase 3c.

The data for Phase 3d was not used. First, the sludge production was higher than for the control. Second, Phase 3d is an atypical phase because the digesters were operating at too low an SRT (SRT = 8.8d, see Table 7).

GENERAL DISCUSSION

In this four-year study, the effect of recycling the thermophilic sludge drawoff from a digester which was operated in series following a mesophilic digester into the aeration system of an activated sludge plant, was investigated. The primary objective of this study was to determine whether such a recycling scheme would yield a net reduction in the quantity of sludge that is ultimately disposed, in comparison to the quantity of sludge disposed from a conventional system that does not operate with such a scheme.

Significant reductions in sludge quantities have been reported in the plants operated by New York City employing such a scheme. Table 23 presents a summary of the results that were reported by Carrio et al (1985). A summary of the results obtained in this study is also provided in this table for comparison.

From Table 23 it can be seen that substantial reductions in the quantity of sludge to be disposed was achieved in the New York City treatment plants either by recycling thermophilic or mesophilic sludge either to the aerators or to the head end of the treatment plants. A much smaller reduction in the quantity of sludge was achieved at the Hanover Park WRP.

Explanations for the differences in performance of the New York City's plants and the Hanover Park WRP, are as follows:

1) An appropriate control was not kept in the New York studies. Data obtained in a "pre-experimental period," during which no sludge recycling took place, were compared with those obtained in an experimental period during which thermophilically digested sludge was recycled through the activated sludge system. The sewage characteristics were different during these periods. Thus any observed differences in production between pre-experimental and experimental period could be due to changes in sewage characteristics. In the Hanover Park WRP studies, appropriate controls were kept and any differences in operational protocols between the control and experimental systems were accounted for.

2) The Hanover Park WRP was operated at a sludge age (Gould's) or SRT far higher than the low sludge ages (Gould's) traditionally practiced at New York City's treatment plants. These plants are operated as modified aeration plants with considerable lower BOD removal efficiencies than those achieved at the Hanover Park WRP. The Hanover Park WRP was operated at high solids retention times as evidenced by

TABLE 23. SLUDGE DISPOSAL AT NEW YORK CITY TREATMENT PLANTS WITH AND WITHOUT RECIRCULATION OF DIGESTED SLUDGE INTO AERATION TANKS AND OUR STUDY

Plants	Sludge Age (days)	g TS/m^3 (lb/mil. gal)	Sludge Disposed (production)		
			g VS/m^3 (lb/mil. gal)	$\frac{\text{g TS}}{\text{g BOD Rem.}}$	$\frac{\text{g TS}}{\text{g SS Rem.}}$
Newton Creek*					
-w/o recirc.	0.51	62.1 (518)	34.3 (286)	0.93	0.89
-w/recirc.	0.36	40.0 (334)	21.9 (183)	0.56	0.44
-w/recirc.	0.32	36.1 (301)	20.2 (169)	0.48	0.40
Oakwood Beach**					
-w/o recirc.	4.3	49.7 (415)	27.8 (232)	0.60	0.50
-w/recirc.	6.2	42.4 (354)	25.0 (209)	0.40	0.46
26th Ward**					
-w/o recirc.	4.4	49.5 (413)	29.6 (247)	0.7	0.68
-w/recirc.	3.9	32.7 (273)	18.3 (153)	0.48	0.68
Bowery Bay*					
-w/o recirc.	4.8	61.6 (514)	37.0 (309)	0.69	0.78
-w/recirc.	6.2	53.6 (447)	32.9 (275)	0.58	0.70
Rockaway***					
-w/o recirc.	3.8	36.9 (308)	21.4 (179)	-	0.58
-w/recirc.	2.3	17.7 (148)	10.4 (87)	0.22	0.31

(continued).

TABLE 23. (CONTINUED)

			Sludge Disposed (production)		
Plants	Sludge Age (days)	g TS/m^3 (lb/mil. gal)	g VS/m^3 (lb/mil. gal)	g TS / g BOD Rem.	g TS / g SS Rem.
This Study					
Hanover Park WRP					
-w/o recirc.++	17	69.2 (578)	44.7 (373)	0.58	0.89
-w/o recirc.@	14	70.6 (589)	43.6 (364)	0.58	0.87
-w/o recirc.++	24	60.4 (504)	40.7 (340)	0.53	0.74
-w/recirc.@@	18	71.8 (599)	40.0 (334)	0.63	0.85
-w/o recirc.++	15	54.1 (452)	32.8 (274)	0.52	0.61
-w/recirc.#	13	77.9 (650)	31.7 (265)	0.75	0.87
-w/o recirc.++	18	52.5 (438)	34.5 (288)	0.53	0.69
-w/recirc.##	14	78.9 (659)	29.9 (250)	0.77	0.97
-w/o recirc.	24	66.0 (551)	41.8 (349)	0.55	0.80
-w/recirc.###	14	146.3 (1,221)	45.3 (378)	1.2	1.66

*Digested sludge recycled to head-end of plant (50% recirculation rate).

**Digested sludge recycled to aerators.

***Digested thermophilic sludge recycled after elutriation to aerators (50% recycle rate).

++Control Section (Aeration Batteries A&B, Digester Nos. 1&3).

@No thermophilic sludge recycling, Experimental Section (Aeration Batteries C&D, Digester Nos. 3&4).

@@Thermophilic sludge recycling at 13 percent to aerators of Experimental Section without elutriation.

#Same as (b) above but at 29.1 percent.

##Same as (b) above but at 40.4 percent.

###Same as (b) above but at 50.7 percent.

complete nitrification. Very high suspended solids and BOD removals were also achieved, unlike the New York City's treatment plants. The sludge produced in treatment systems operating at high sludge ages or SRTs would have considerably lower endogenous substrate reserves than the sludge produced in a high rate activated sludge system operating at low sludge ages or SRTs. Thus, sludges produced at low sludge ages would have higher biodegradability potential than those produced at high sludge ages. The values of the kgs of suspended solids produced for a kg of raw sewage BOD removed in the New York City treatment plants indicate a range of 0.6 to 0.98. These sludge yields are considerably higher than the values of 0.52 to 0.55 kgs SS/kg BOD removed at the Hanover Park WRP.

The New York sludges, which are likely to have a high biodegradability potential, may have enough biodegradable solids still left in them even after they are subjected to anaerobic digestion. When these solids are recycled through the activated sludge and anaerobic digestion processes once again, additional solids would be lost resulting in a lower sludge mass than in a system where such recycling scheme is not practiced.

It is likely that the situation is different at the Hanover Park WRP. In view of the observed significant reduction of sludge solids reported in the New York studies and the lack of it in this study, it is likely that the New York City's anaerobically digested sludges contained a considerably higher quantity of biodegradable solids in them than the anaerobically digested sludge of the Hanover Park WRP.

3) In the case of the Rockaway Sewage Treatment Plant of New York City, an elutriation step was employed prior to the recycling of thermophilic sludge to the aeration tanks. This step is noted for removing the fines from the thermophilic sludge and may have also contributed to additional loss of solids. This step was not employed in the Hanover Park WRP study.

The digestion of the waste activated sludge and primary sludge occurring at the Hanover Park WRP in a mesophilic-thermophilic digester system, evidently produced a well-stabilized sludge. This sludge when recycled through the aeration tanks, resulted in no further reduction of solids. The sludge solids that were recycled to the aeration tanks ultimately returned to the digesters and passed through them without any significant reduction in mass.

The observed volume reduction in sludge that is ultimately disposed from the New York City treatment plants is evidently also due to the elutriation and storage/decanting operations that the digested sludge is subjected to. In our study, the digested drawoffs were not subjected to such operations. The entire volume of sludge that was recycled to the aeration batteries eventually returned to the digesters and ultimately disposed of on the farm. As a consequence of recycling sludge into aeration tanks and returning back to the digesters, the detention time of the digesters in the experimental section decreased as the volume of the sludge recycled to the aeration tanks increased.

From the foregoing observations and considerations, it can be concluded that an incorporation of the different sludge recycling protocols that have been practiced at the New York City's treatment plants may be advantageous for application in achieving sludge mass reductions in plants operating at low sludge ages (high food:micoorganisms ratios) i.e., under the modified or high rate activated sludge regimens. This study showed that no significant reductions in sludge quantities will be accomplished in plants that operate at high sludge ages (low food:microorganisms ratios and nitrifying conditions) by employing sludge recycling protocols similar to those practiced in the New York City treatment plants.

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APPENDIX A

QUALITY ASSURANCE PROGRAM FOR LABORATORY DATA

THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO

DEPARTMENT OF RESEARCH AND DEVELOPMENT

REPORT NO. 85-12

QUALITY ASSURANCE PROGRAM FOR LABORATORY ANALYTICAL DATA

E. Bogusch
C. Lue-Hing
D.W. Harper

June 1985

THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO

QUALITY ASSURANCE PROGRAM FOR LABORATORY ANALYTICAL DATA

By

Eugene Bogusch
Sanitary Chemist III

Cecil Lue-Hing
Director

Donald W. Harper
Head of Analytical Laboratories

Research and Development Department

June 1985

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OVERALL OBJECTIVES

The Metropolitan Sanitary District of Greater Chicago (District) has maintained a quality assurance program to validate all data from its laboratories. The accuracy of its data is essential for the following reasons:

1. To monitor the environmental quality of waterways within the jurisdiction of the District.
2. To characterize the wastewater received by the District's treatment facilities.
3. To determine the pollutional load of its treatment facility effluent on receiving waterways and determine compliance with effluent restrictions.
4. To access the effectiveness of various stages of the treatment processes at each facility.
5. To support a wide variety of research projects, many of which are directed at increasing the efficiency of wastewater treatment of reducing operational costs.
6. To determine compliance of regulated industrial discharges to receiving waterways in order to maintain their environmental quality.
7. To determine compliance of regulated industrial discharges to the District's sewer system in order to protect the operation of its treatment facilities and maintain satisfactory effluents.

QUALITY ASSURANCE AT THE WORKBENCH

The District's quality assurance program begins with the employment of highly qualified personnel who have demonstrated their competency through an appropriate civil service examination. All analysts are trained for each assigned analytical procedure by an experienced staff chemist. The performance of each analyst is formally reviewed every six months.

The majority of analytical methods employed at District laboratories are prescribed by _Standard Methods for the Examination of Water and Wastewater_ (1981) or USEPA _Methods for Chemical Analysis of Water and Wastes_ (1979). Generally, every effort is made to follow these procedures exactly. The District will, on occasion, depart from these prescribed methods in order to utilize more sophisticated or automated analytical instruments, or to utilize newly developed methods of analysis, some of which are developed by the District's Methodology Section, i.e., cyanide and phenol analysis.

District laboratories continuously monitor the accuracy and precision of each analytical procedure. Control limits for acceptable results are periodically calculated at 95 percent confidence levels for both accuracy and precision. Check standards for both accuracy and precision are run every ten samples. The results are plotted daily on control charts to alert the analyst of any abnormal situation. The detailed procedure used by the analytical laboratory personnel for analytical quality assurance at the workbench is as follows:

Control Limit Evaluation

1. Control limits shall be reevaluated at least annually, and more frequently if control checks do not exceed the 95 percent warning limits approximately 5 percent of the time.
2. Control limits shall be evaluated by the RS/1 computer programs which determine limits by calculation of standard deviation. For accuracy, warning limits are calculated at 95 percent probability and control limits are calculated at 99.96 percent. For precision, a variable warning limit dependent on concentration is calculated at 95 percent probability.
3. Data for accuracy, precision, and standard addition samples shall be kept on forms made by, or approved by, the quality assurance coordinator. Information pertaining to calculation of control limits should be kept on standard forms and be readily available.
4. Normally, all data from the most recent calendar period selected should be used for control limit evaluation. This includes data from confirmed out-of-control periods as long as it is typical of the overall results of the analysis.
5. Control limits can be evaluated for almost any amount of data. Generally, better estimates of control limits are obtained if more data values are used. The optimum number of data values is 75 to 250.

Control Charts

1. Control charts should be used on all designated parameters. One control chart is required for accuracy and another for precision. If no standard for accuracy exists, then only a control chart for precision is required.
2. For best data interpretation, both accuracy and precision should be plotted on the same sheet of graph paper, with accuracy above precision. If plotted on the same paper, use different plot symbols for each graph. If desired, however, accuracy and precision may be plotted on separate sheets of graph paper.
3. All control charts shall be plotted serially. Calendar dates shall be indicated in monthly intervals.
4. Control charts should indicate at appropriate intervals, monthly or bimonthly, the percent of check samples exceeding control limits. If approximately 5 percent of the check samples do not exceed the warning limits, then the control charts may not be providing the analyst an accurate depiction of analysis performance. When this occurs, the control limits should be recalculated.
5. Control charts must be plotted daily and analysts are expected to act promptly as outlined in Section 5, "Use of Control Charts".

6. Control charts must be neat, legible, and readily available.

7. All analysts, as well as their supervising chemists, are expected to:
    1. Be familiar with the control charts of the analysis they are working on.
    2. Be able to perform the charting.

Accuracy

1. Control charts for accuracy should have the following five lines drawn and clearly indicated:

    Upper Control Limit - 99.98 percent probability
    Upper Warning Limit - 97.5 percent probability
    Average Percent Recovery
    Lower Warning Limit - 2.5 percent probability
    Lower Control Limit - 0.02 percent probability

    Use broken lines to indicate the warning limits and solid lines for the control limits.

2. Accuracy is plotted as percent recovery:

$$\frac{\text{Analyzed Value}}{\text{True Value}} \times 100$$

3. Accuracy check standards should not be run consecutively but at regular intervals.

4. A minimum of two accuracy check standards should be run for any analysis performed on any given day. The first and last aliquots in any sample run should be accuracy checks.

5. An accuracy check standard should be run with a minimum frequency of every ten samples.
6. The concentration of accuracy check standards should be near, or greater than, the midpoint of the working analytical concentration range of the analysis. Note that a change of the check standard concentration may require a recalculation of accuracy control limits.
7. Blanks with reagents should also be run at regular intervals, or with each batch of samples.

Precision

1. Since precision is generally concentration dependent, control charts for precision ordinarily will not have drawn lines to indicate a precision limit. However, a single precision warning limit may be drawn if the limit evaluation shows that precision is not concentration dependent.
2. Precision is plotted as:

   /Analyzed Value #1 - Analyzed Value #2/
3. Precision data shall be obtained by duplicate analysis of real samples at regular intervals. Different samples should be used for each precision check. Precision samples which are not of extremely low values should be selected whenever possible.
4. A minimum of one duplicate analysis on a real sample should be run for any analysis performed on any day.

5. A minimum of one duplicate analysis should be performed for every ten samples.
6. One duplicate sample analysis for precision should be made between every two accuracy check standards. The two analyses should not be consecutive, and should be separated by at least five samples whenever possible.
7. If all samples are routinely run in duplicate, then any sample may be used for the precision check.
8. Precision should be checked against the precision limit chart - a plot of the precision warning limit versus sample concentration. This graph may be obtained by plotting the linear regression line calculated by the control limit program. If the precision warning limit determined from the precision limit chart is exceeded, then the plotted value should be circled on the control chart.

Use of Control Charts

1. With 95 percent accuracy warning limits, 1 in 20 accuracy checks will exceed the warning limits due to normal statistical variation.
2. The following three conditions will indicate an out-of-control situation:
    1. The 99.96 percent accuracy control limits are exceeded. Corrective action - rerun all samples to the last acceptable accuracy check.

    2. Two or more consecutive accuracy check standards exceed the 95 percent warning limits. Corrective action - rerun all samples to the last acceptable accuracy check.
    3. Any nine successive accuracy checks fall on the same side of the average percent recovery line on the control chart. Corrective action - the cause of the bias should be determined and corrected.

3. The analyst should inform the analytical section supervisor of any accuracy check standards which exceed either the warning or the control limits, as quickly as possible, so that appropriate action can be taken.
4. A log of out-of-control occurrences should be maintained for every analysis. This log should contain the following information: date, control limit, analyzed result, true value, percent recovery, and action taken.
5. A rerun of a sample is in agreement with the original analysis if the precision of both results does not exceed the precision limit as determined in Number 8 under Precision. If the original analysis is verified by the recheck, the analyst should report the average of the two results. If the original result and rerun fail to meet the precision limit, then the rerun result should be reported.

6. Analyses exempted from reruns are:
    1. Those with time restraints such as BOD
    2. Those with limited sample volume such as FOG

   However, the analyst still must investigate and document the out-of-control situations described in Number 2 of this section.
7. For analysis without accuracy control charts, criteria for determining out-of-control situations will be established individually.
8. The analyst will rerun any sample which he suspects may be in error even though the accuracy and precision checks are normal.

Standard Addition

1. Spiked samples should be run at least once weekly for any analysis with an accuracy control chart.
2. Results for spiked samples should be calculated as percent recovery.

$$\frac{\text{Analyzed Value} - \text{Original Sample Value}}{\text{Spike Value}} \times 100$$

3. Samples with relatively low concentrations should be used for spiking.
4. A spike value should be near the midrange of the working analytical concentration range of the analysis.
5. The result of the spiked analysis should be plotted on the accuracy control chart using a different plot symbol than for routine accuracy checks.

Calibration Curves

For analyses without internal instrument calibration.

1. Calibration curves should be remade at least twice yearly.
2. Calibration curves should be remade with each new batch of reagents.
3. At least five, and preferably seven, standards should be used to make a calibration curve.
4. Daily checks of calibration curves must be within ± 10 percent.

INTERLABORATORY QUALITY ASSURANCE AT THE DISTRICT

The District has maintained an internal quality assurance program to routinely evaluate the analytical performance of all its regional quality control laboratories (West-Southwest, Calumet, and Egan), its Industrial Waste Laboratory at West-Southwest, and its Soil Research Laboratories (West-Southwest, and Fulton County). In addition, the program also checks the performance of any laboratory contracted to do analytical work for the District.

Each participating laboratory is given check samples every three months. Thirty-six parameters are presently included in the program. These check samples are prepared in distilled water using certified concentrations from the USEPA. The laboratories analyze these samples without knowing the true concentrations. The results are evaluated for precision and accuracy by the District's Methodology Section. The results from all laboratories are reviewed by each laboratory and in joint meetings between laboratories.

This program serves the following functions:

1. Establishes levels of accuracy and precision for each analytical procedure evaluated.
2. Alerts each laboratory to its relative performance in comparison with other District laboratories.
3. Aids in uniformity of execution of analytical procedures between laboratories.

4. Raises the consciousness of quality control at each laboratory which results in improved efficiency and accuracy throughout the entire laboratory system.

INTERLABORATORY PERFORMANCE EVALUATION WITH OTHER AGENCIES

The District participates in performance evaluation studies conducted by other governmental agencies. In the last quarter of 1984, all three District regional quality control laboratories took part in a National Pollutant Discharge Elimination System (NPDES) laboratory performance evaluation study conducted by the United States Environmental Protection Agency (USEPA).

On a semi-annual basis, the District participates in a USEPA Region V laboratory performance evaluation study. Only the West-Southwest laboratory is included in this study.

In the third quarter of 1980, the West-Southwest Laboratory completed a multi-year performance evaluation study with the United States Geological Survey (USGS). This study was undertaken to support our cooperative effort with the USGS in furnishing analytical data of water quality in our waterways system and of groundwater quality at our Fulton County land reclamation site.

The District expects to secure certification of its three regional quality control laboratories by the Illinois Environmental Protection Agency (IEPA) when the state certification program is implemented. An application was submitted on October 12, 1980. Certification as an environmental laboratory requires that a laboratory meet and maintain all standards specified by the IEPA. A certified environmental laboratory must also participate in annual performance evaluations for those analytical parameters for which it is certified.

APPENDIX B

PERFORMANCE EVALUATION REPORTS FOR HANOVER PARK WRP ANALYTICAL PRAMETERS (NPDES PERMITTEE NO. IL0036137-7/16/85 AND 7/09/86

PERFORMANCE EVALUATION REPORT DATE: 07/16/85

DMR-QA STUDY NUMBER 005

PERMITTEE: IL0036137 MSD OF GREATER CHICAGO - HANOVER PK WRP

PARAMETERS	V P	REPORT VALUE	TRUE VALUE*	ACCEPTANCE LIMITS	WARNING LIMITS	PERFORMANCE EVALUATION
TRACE METALS IN MICROGRAMS PER LITER:						
ARSENIC		86	84.1	59.3- 108.	65.8- 102.	ACCEPTABLE
CADMIUM		405	391	345.- 441.	357.- 429.	ACCEPTABLE
CHROMIUM		62	66.2	48.9- 82.5	53.2- 78.2	ACCEPTABLE
COPPER		685	694	606.- 764.	626.- 744.	ACCEPTABLE
IRON		1576	1558	1320.-1780.	1380.-1720.	ACCEPTABLE
LEAD		249	250	198.- 300.	211.- 287.	ACCEPTABLE
MANGANESE		802	803	704.- 888.	728.- 864.	ACCEPTABLE
MERCURY		7.3	7.19	4.47- 9.77	5.17- 9.08	ACCEPTABLE
NICKEL		288	288	244.- 330.	255.- 319.	ACCEPTABLE
SELENIUM		62	60.6	31.5- 78.9	37.8- 72.6	ACCEPTABLE
ZINC		203	201	168.- 234.	176.- 225.	ACCEPTABLE
MISCELLANEOUS PARAMETERS:						
PH-UNITS		5.99	6.00	5.85- 6.13	5.89- 6.10	ACCEPTABLE

* BASED UPON THEORETICAL CALCULATIONS, OR A REFERENCE VALUE WHEN NECESSARY.

PERFORMANCE EVALUATION REPORT DATE: 07/16/85

DMR-2A STUDY NUMBER 005

PERMITTEE: IL0036137 MSD OF GREATER CHICAGO - HANOVER PK WRP

PARAMETERS	V P	REPORT VALUE	TRUE VALUE*	ACCEPTANCE LIMITS	WARNING LIMITS	PERFORMANCE EVALUATION
MISCELLANEOUS PARAMETERS:						
TOTAL SUSPENDED SOLIDS (IN MG/L)		84.8	95.3	77.4- 106.	81.0- 103.	ACCEPTABLE
NUTRIENTS IN MILLIGRAMS PER LITER:						
AMMONIA-NITROGEN		3.09	3.10	2.42- 3.72	2.58- 3.56	ACCEPTABLE
DEMANDS IN MILLIGRAMS PER LITER:						
5-DAY BOD		90.0	83.5	43.0- 113.	52.0- 104.	ACCEPTABLE

* BASED UPON THEORETICAL CALCULATIONS, OR A REFERENCE VALUE WHEN NECESSARY.

PAGE 2 (LAST PAGE)

PERFORMANCE EVALUATION REPORT

DATE: 07/09/86

DMR-QA STUDY NUMBER 006

PERMITTEE: IL0036137 MSD OF GREATER CHICAGO - HANOVER PK LX

ANALYTES	V P	REPORT VALUE	TRUE VALUE*	ACCEPTANCE LIMITS	WARNING LIMITS	PERFORMANCE EVALUATION
TRACE METALS IN MICROGRAMS PER LITER:						
ARSENIC		300	342	244.- 419.	266.- 397.	ACCEPTABLE
CADMIUM		312	307	269.- 348.	279.- 338.	ACCEPTABLE
CHROMIUM		270	274	213.- 331.	227.- 316.	ACCEPTABLE
COPPER		386	380	332.- 422.	344.- 411.	ACCEPTABLE
IRON		1315	1311	1120.-1480.	1170.-1440.	ACCEPTABLE
LEAD		116	118.8	89.0- 146.	96.1- 139.	ACCEPTABLE
MANGANESE		512	510	448.- 564.	463.- 550.	ACCEPTABLE
MERCURY		52.8	50.0	34.4- 65.9	38.3- 61.9	ACCEPTABLE
NICKEL		521	532	460.- 605.	479.- 587.	ACCEPTABLE
SELENIUM		56.	54.9	32.6- 66.9	36.9- 62.6	ACCEPTABLE
ZINC		386	383	333.- 429.	345.- 417.	ACCEPTABLE
MISCELLANEOUS ANALYTES:						
PH-UNITS		6.67	6.70	6.54- 6.83	6.58- 6.80	ACCEPTABLE

* BASED UPON THEORETICAL CALCULATIONS, OR A REFERENCE VALUE WHEN NECESSARY.

PERFORMANCE EVALUATION REPORT DATE: 07/09/86

DMR-QA STUDY NUMBER 006

PERMITTEE: IL0036137 MSD OF GREATER CHICAGO - HANOVER PK LX

ANALYTES	V P	REPORT VALUE	TRUE VALUE*	ACCEPTANCE LIMITS	WARNING LIMITS	PERFORMANCE EVALUATION
MISCELLANEOUS ANALYTES:						
TOTAL SUSPENDED SOLIDS (IN MG/L)		34.	35.6	26.6- 37.5	28.0- 36.1	ACCEPTABLE
NUTRIENTS IN MILLIGRAMS PER LITER:						
AMMONIA-NITROGEN		4.43	4.60	3.68- 5.49	3.90- 5.28	ACCEPTABLE
DEMANDS IN MILLIGRAMS PER LITER:						
5-DAY BOD		69.3	63.8	40.4- 87.3	46.2- 81.5	ACCEPTABLE
ADDITIONAL MISCELLANEOUS ANALYTES:						
TOTAL CYANIDE (IN MG/L)		0.95	1.05	.609- 1.36	.706- 1.27	ACCEPTABLE
TOTAL PHENOLICS (IN MG/L)		0.298	0.277	.115- .438	.155- .398	ACCEPTABLE
TOTAL RESIDUAL CHLORINE (IN MG/L)		1.20	1.14	.721- 1.49	.820- 1.40	ACCEPTABLE

* BASED UPON THEORETICAL CALCULATIONS, OR A REFERENCE VALUE WHEN NECESSARY.

PAGE 2 (LAST PAGE)

APPENDIX C

QUALITY ASSURANCE AUDIT REPORT
PEI ASSOCIATES, CINCINNATI, OHIO, 9/25/85

PEI ASSOCIATES, INC.
(FORMERLY PEDCo ENVIRONMENTAL, INC.)

11499 CHESTER ROAD
CINCINNATI, OHIO 45246
(513) 782-4700
TELECOPIER (513) 782-4807

QUALITY ASSURANCE AUDIT REPORT

Project: The Effective Recycling of Sludge From Mesophilic and Thermophilic Digesters, Task I.D. WWA95

Project Officer: Dr. Joseph Farrell

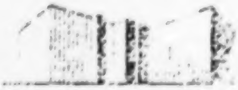
Cooperative Agency: Metropolitan Sanitary District of Greater Chicago

Project Location: Chicago, Illinois

Audit Date: 9-25-85

Audit performed under Contract No. 68-03-3209

Work Assignment No. 4., PN 3620-4



CHESTER TOWERS

BRANCH OFFICES

DALLAS, TEXAS
DENVER, COLORADO
COLUMBUS, OHIO
DURHAM, NORTH CAROLINA
KANSAS CITY, KANSAS

QUALITY ASSURANCE AUDIT NARRATIVE

Project: The Effective Recycling of Sludge From Mesophilic and Thermophilic Digesters, Task I.D. WWA95

Project Officer: Dr. Joseph Farrell

Cooperative Agency: Metropolitan Sanitary District of Greater Chicago

Project Location: Chicago, Illinois

Audit Date: 9-25-85

Audit Participants: Dr. T. B. S. Prakasam, Principal Investigator
Mr. Ed Shepard, Laboratory Director
Mr. Howard Baument, Laboratory QAO
Tom Wagner, PEI

The audit consisted of a meeting in Mr. Shepard's office with the other audit participants. The purpose and scope of the audit was explained and status report of the project was received. A tour of the laboratory facility and a second meeting in a conference room to review the questionnaire and quality control records was conducted.

The actual measurements have not yet commenced because the thermophilic digester is currently being raised to the desired temperature level. Several initial comparisons have been completed. A control comparison of the two systems have been completed with both systems operating at same conditions. A study has been completed to determine that different operators on various shifts obtain comparable samples from the systems.

The attached Technical Systems Audit Form was completed based on the observation of the procedures used for routine samples in the laboratory. These are the same procedures which will be used during this project.

The Laboratory has an established Quality Control program. A copy of this document is attached. The laboratory received daily samples from each of the District's plants. These samples are inspected by the QAO upon receipt and the analyses are started immediately. The results of QC samples for precision and accuracy are recorded daily on Quality Assurance Bench Data Sheets (example attached) and plotted on control charts (example attached). These results are reviewed by the Supervisor and compiled in a weekly summary by the QAO. These QC forms were available for each analysis.

The QAO prepares the control samples for accuracy. The method and amounts used are contained in a notebook and then summarized on a data sheet for easy reference. The QA system appears to be well established and implemented.

The field site is at a remote location and was not inspected. The principal investigator is conscious of the need for adequate QA at the sampling end. The preliminary studies were conducted for this reason.

Overall the QA/QC system that is in place should allow the acquisition of data of adequate quality for purpose of this project.

Location: Chicago, Ill
Project:
Date: 9-25-85

TECHNICAL SYSTEMS AUDIT PROTOCOL

A. General

Yes [✓ No] N/A	1. Is a written and approved quality assurance Project Plan available for each project? Contained in proposal - QA Program

B. Laboratory Procedures

[✓ Yes] No N/A	1. Is calibration of instruments and equipment satisfactory?
	2. Duplicate samples are analyzed 10 % of time.
	3. Spiked samples are used ____ % of time. → weekly.
[✓ Yes] No N/A	4. Does the laboratory participate in interlaboratory quality control checks or performance evaluations such as the Intercomparison Program conducted by the Environmental Monitoring Systems Laboratory, Las Vegas/ORD. WP - 1/yearly

C. Laboratory Facilities and Equipment

[✓ Yes] No N/A	1. Is proper grade distilled water available for specific analysis?
Yes No N/A	2. Does fume hood have enough ventilation capacity?
[✓ Yes] No N/A	3. Does laboratory have sufficient lighting?
[✓ Yes] No N/A	4. Are instruments/equipment in operating condition?
Yes No N/A	5. Are written trouble-shooting SOPs for instruments available?
[✓ Yes] No N/A	6. Does a schedule for required maintenance exist?
[✓ Yes] No N/A	7. Is proper volumetric glassware used?
[✓ Yes] No N/A	8. Is glassware properly cleaned according to a laboratory SOP?
[✓ Yes] No N/A	9. Are QC procedures for maintaining and servicing equipment available and are records kept for major items (performance specs, acceptance procedures, maintenance records, etc.)?
[✓ Yes] No N/A	10. Are QC procedures available and records kept for consumables (purity, shelf-life records, acceptance testing, etc.)?

Yes No N/A	11. Are QC procedures available and records kept for services (water purity, hoods, metrology, etc.)
[✓ Yes] No N/A	12. Are inspections and maintenance of facilities and equipment conducted regularly? If so, by whom? Howard Baumert Who receives these reports? Eugene Boguech
[✓ Yes] No N/A	13. Does QAO inspect records for equipment, consumables, and services? If so, how frequently and what corrective action is taken where so indicated?
[✓ Yes] No N/A	14. How often are balances calibrated? 2 times a year inspection
[✓ Yes] No N/A	15. Are measurement devices, (i.e., pH meters, automatic pipettes, etc.) calibrated before use?

D. Sampling

sampling hasn't started yet

	1. What can be deduced about representativeness of samples collected? Not observed – Is sampling site(s) location random or specific? Specific If random, what was statistical rationale? If specific, what factors influenced site selection? Determined by Process
[✓ Yes] No N/A	2. Is duration of sampling sufficient to detect all important pollutant(s) generated by the process under investigation?
[✓ Yes] No N/A	3. Are number of samples collected sufficient to satisfy the completeness requirements specified in QA Project Plan?
Yes [✓ No] N/A	4. Were replicate samples taken for each sampling site? 24 hour composite.
	5. How are integrity of samples maintained? – Type of container used Plastic – Type of preservation used None Transported to lab immediately – Type of field spike(s) used NONE – Type of field blank(s) used NONE – Type of trip blank(s) used NONE After composite is completed, samples are transported to laboratory 30 minute trip. Analyses start on the same day received.
[✓ Yes] No N/A	6. Was sampling performed in accordance with a lab approved QA Project Plan?
[✓ Yes] No N/A	7. Were uniform procedures followed throughout for collection of field blanks, container clean-up, and preservation of samples?

[✓ Yes] No N/A	8. Were samples adequately labeled and were custody requirements, as specified in in the QA Project Plan, implemented?
Yes [✓ No] N/A	9. Is there a Standard Operating Procedure or other source of documentation which describes the organization's sample custody procedures? Received, inspected by QAO, then analysis started the same day.
[✓ Yes] No N/A	10. Are records available of when the sample was collected?
Yes No N/A	11. Are records available of who collected sample? 24 hour composite (3 operators
[✓ Yes] No N/A	12. Are records available of how sample was collected?
[✓ Yes] No N/A	13. Are records available of where sample was collected and what it is?
[✓ Yes] No N/A	14. Are records available of how the samples were prepared and transported to laboratory?
[✓ Yes] No N/A	15. Are records available of when the samples were prepared and transported to laboratory? same day and sample
Yes [✓ No] N/A	16. Are records available of who prepared and then transported the sample?
Yes [✓ No] N/A	17. Is there someone designated to be the sample custodian (log-in samples and track samples)?
[✓ Yes] No N/A	18. Is there a designated receipt location for samples for the laboratory?
[✓ Yes] No N/A	19. Is the condition of the sample upon receipt and date of receipt documented?
[✓ Yes] No N/A	20. Are samples individually identified by number or code so that they can be traced?
Yes [✓ No] N/A	21. Are samples permanently labeled upon receipt? (labeled during sampling)
[✓ Yes] No N/A	22. Are records available as to how sample was stored upon receipt? not stored
[✓ Yes] No N/A	23. Is there a system for documentation of the history of the sample after it has been logged into the laboratory?
Yes No N/A	a. individuals handling the sample (for instance to take subsample) identified?
Yes No N/A	b. placing sample into another container?
Yes No N/A	c. the date (a) was performed?
Yes No N/A	d. amounts removed from sample recorded?
Yes No N/A	e. the procedure(s) used to obtain subsample?
[✓ Yes] No N/A	24. Are records available of when sample was extracted? Volatile acids only
[✓ Yes] No N/A	25. Are records available of when sample was analyzed?
[✓ Yes] No N/A	26. Are records available of who extracted sample?

[✓ Yes] No N/A	27. Are records available of who analyzed sample?
Yes No N/A	28. Are records available on preparation of sampling containers or sampling media?
[✓ Yes] No N/A	29. Are extracts of samples labeled?
Yes No N/A	30. Are extraction/reaction containers labeled during chemical work-up?
Yes No N/A	31. If autosamplers are used, are sample vials labeled?
Yes No [✓ N/A]	32. Once analyses has been completed, are records available of the fate of the remainder of the sample (storage, disposal)?
Yes No [✓ N/A]	33. Is there a policy or protocol in place for when and how samples are disposed of after completion of analysis?
[✓ Yes] No N/A Yes No N/A	34. Was the SOP or other protocol describing sample custody followed? If not, were the deviations documented?

E. Analysis

[✓ Yes] No N/A	1. Was analysis performed in accordance with the QA Project Plan approved by EPA?
[✓ Yes] No N/A	2. How much time elapsed between sample collection and analysis? hours Was this within the prescribed limits specified in the QA Project Plan?
[✓ Yes] No N/A	3. Under what conditions were samples stored prior to analysis (i.e., temperature, light, humidity, etc.)? Refrigerated Were these within the prescribed limits specified in the QA Project Plan?
Yes [✓ No] N/A Yes No N/A	4. Were samples spiked in the field? Are recoveries within acceptable limits?
[✓ Yes] No N/A	5. Are instruments calibrated prior to analysis?
Yes No N/A	6. Are QC procedures specified in the QA Project Plan being implemented (e.g., frequency of spikes, method blanks, check samples, method calibration standards, etc.)?
[✓ Yes] No N/A	7. Are sample preparation/extraction procedures documented and implemented accordingly?
[✓ Yes] No N/A	8. Are analytical procedures and associated SOPs documented and implemented accordingly?
	9. What method and checks are used in sample calculations for data quality? Check daily by group leader

Yes No N/A	10. If corrective action is warranted, what mechanisms exist for assuring effectiveness of corrective action? QAO has final approval
Yes No N/A	11. What has been the Lab's record on the last two performance evaluation (PE) studies? Not available to me
[✓ Yes] No N/A	12. Are control samples introduced into the train of actual samples to ensure that valid data are being generated?
Yes [✓ No] N/A	13. Were field spikes used to assess loss due to storage, handling and chemical analysis?
[✓ Yes] No N/A	14. Are the identities of the specific instruments used in the study documented?
[✓ Yes] No N/A	15. Are SOP's available on instrument operations, maintenance and calibration?
[✓ Yes] No N/A	16. Are appropriate SOP's available to respond to instrument failure?
[✓ Yes] No N/A	17. Is the response of the instrument in the concentration range of the samples?
[✓ Yes] No N/A	18. Are conditions of the instrument for the analysis recorded, i.e., temperature, chart speed or time, sample number, column, solvent, volume, etc., such that the conditions are known for each result?
Yes No [✓ N/A]	19. Is an instrument log or record maintained describing when instrument was used and its condition during the period each result was analyzed?
[✓ Yes] No N/A	20. Is there a record of the amount of sample analyzed by the instrument?
[✓ Yes] No N/A	21. Are dilutions or preparation of the sample for instrumental analyses documented?
Yes No [✓ N/A]	22. If microprocessors or laboratory data management systems are used with GCs or HPLCs, are hard copies of chromatographs available?
Yes No [✓ N/A]	23. If microprocessors or laboratory data management systems are used with GCs or HPLCs, can the nature of the baseline be determined?
Yes No [✓ N/A]	24. Are instrument logs signed, initialed or in some manner can you identify the individual who made an entry?

[✓ Yes] No N/A	25. If problems arise with instrument performance, do instrument logs or records, record:
Yes No N/A	a. identity of the problem?
Yes No N/A	b. how the problem was discovered?
Yes No N/A	c. when the problem was discovered?
Yes No N/A	d. the action taken to correct the problem?

F. Standards and Reagents

[✓ Yes] No N/A	1. Are standards available to perform daily check procedures?
[✓ Yes] No N/A	2. Is the source of the standards or reference materials documented for each result?
[✓ Yes] No N/A	3. Is the purity of the standards used to obtain the results documented?
[✓ Yes] No N/A	4. Are standard solutions, reagents, and solvents labeled in a manner such that:
[✓ Yes] No N/A	a. the preparers can be identified?
[✓ Yes] No N/A	b. the dates prepared can be ascertained?
[✓ Yes] No N/A	c. notebook description of preparation can be found?
	d. identity of substance is known?
	e. purity or concentration is known?
	f. storage requirements are known?
	g. expiration date known?
[✓ Yes] No N/A	5. Are records retained for the source of standard solutions, solvents, reagents, etc.
[✓ Yes] No N/A	6. Are records available for the purity of solvents, reagents, etc., used in this study?
[✓ Yes] No N/A	7. Are standard reagents and solvents properly stored?
[✓ Yes] No N/A	8. Are working standards frequently checked? How often?
Yes No N/A	9. Are standards discarded after recommended shelf life has expired?
[✓ Yes] No N/A	10. Are background reagents and solvents run with every series of sample?
Yes No [✓ N/A]	11. Do written procedures exist for cleanup, hazard response methods, and applications of correction methods for reagents and solvents?

G. Laboratory Personnel

[✓ Yes] No N/A	1. Does the analyst have appropriate training?
[✓ Yes] No N/A	2. Does the analyst follow the specified procedures?
[✓ Yes] No N/A	3. Is the analyst skilled in performing analyses?

J. Egan QC Lab

Quality Assurance Bench Data Sheet for: TKN

Mo: Sept - Yr: 85 Method: EPA 351.2

Plot* Precision Control Limit: * Accuracy LCL: UCL: *

Analyst	Run Date	Pair Date	Pair Source	Plot #	1st Value	2nd Value	Range	Sample Value	True Value	% Recovery	
JM	9/16	9/14	ER	1	51.1	51.5	0.4	14.1	14.3	98.6	
			001	2	3.0	3.4	0.4	13.8		96.5	
				3				13.7		95.8	✓JM
JM	9/17	9/15	ER	4	45.7	44.2	1.5	14.4		100.7	
			001	5	3.6	3.6	0.0	14.3		100.0	
				6				14.4		100.7	✓JM
JM	9/15	9/16	ER	7	50.2	51.7	1.5	13.9		97.2	
			001	8	3.8	3.8	0.0	13.1		91.6	
				9				13.7		95.8	✓JM
JM	9/19	9/17	ER	10	53.0	54.7	1.7	14.6		102.1	
			001	11	2.4	2.8	0.4	14.1		98.6	
				12				14.3		100.0	✓JM
JM	9/20	9/18	ER	13	32.1	32.0	0.1	14.3		100.0	
			001	14	2.5	2.7	0.2	13.8		96.5	
				15				13.9		97.2	
JM	9/23	9/19	ER	16	41.9	43.9	2.0	14.1		98.6	
			001	17	1.4	1.6	0.2	13.5		94.4	
				18				14.0		97.9	✓JM
JM	9/24	9/22	ER	19	9.7	9.3	0.4	14.1		98.6	
			001	20	2.9	2.8	0.1	13.4		93.7	
				21				13.7		95.8	
				22							
				23							
				24							
				25							
				26							
				27							
				28							
				29							
				30							
				31							

NOTE: List Observed Spike under Accuracy if applicable; List IQCP replicates under Precision, Average under Accuracy.

NOTE: Circle OCL events; Notify QA Supervisor; Note action taken on reverse +/or Section Log.

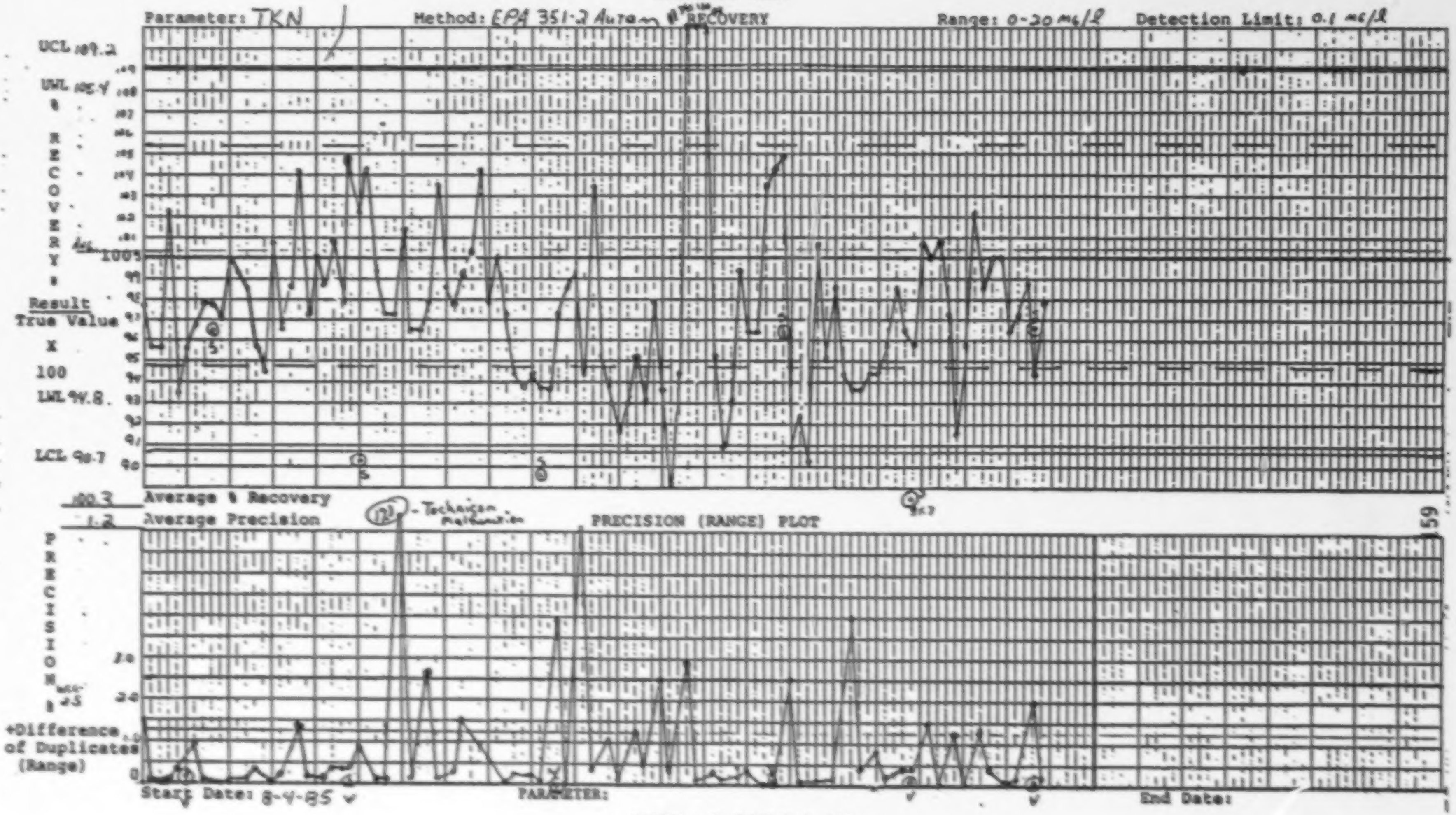
TKN

MSDGC - J. EGAN Q.C. LAB

MSDGC
J. EGAN LAB Q.C.

ACCURACY PLOT

Parameter: TKN
Method: EPA 351.2 Autom
% RECOVERY
Range: 0-20 mg/l
Detection Limit: 0.1 mg/l



100.3 Average % Recovery
1.2 Average Precision

Start Date: 8-4-85
PARAMETER:
End Date:

MSDGC - J. EGAN Q.C. LAB
T.K.N.

APPENDIX - D

AVERAGE MONTHLY DATA OF VARIOUS PHASES FOR THE CONTROL AND EXPERIMENTAL SECTIONS (ENGLISH AND METRIC UNITS)

APPENDIX TABLES D-1 THROUGH D-5
(ENGLISH AND METRIC UNITS)

APPENDIX TABLE D-1 (PART 1)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
RAW SEWAGE						
Flow Rate, mgd						
A	1.02	1.19	1.47	1.13	1.23	1.21
B	2.04	2.51	2.54	2.04	2.40	2.71
C	2.26	2.21	2.57	1.92	2.25	2.44
D	1.87	2.08	2.82	1.91	2.25	2.44
Flow Rate, cu.m/d						
A	3,861	6,504	5,564	4,277	4,656	6,580
B	7,721	9,500	9,614	7,721	9,084	10,257
C	8,554	8,365	9,727	7,267	8,516	9,235
D	7,078	7,873	10,676	7,229	8,516	9,235
Flow Rate, mgd						
A & B	3.06	3.70	4.01	3.17	3.63	3.92
C & D	4.12	4.29	5.39	3.83	4.50	4.88
Flow Rate, cu.m/d						
A & B	11,582	14,005	15,178	11,998	13,740	14,837
C & D	15,594	16,238	20,401	14,497	17,033	18,471
Suspended Solids, mg/l	71	95	85	109	111	84
Volatile Suspended Solids, mg/l	60	79	69	89	92	70
BOD, mg/l	128	137	111	139	127	112
NH4-N, mg/l	18.5	16.0	13.7	19.6	18.9	18.5
AERATION BATTERIES						
HRT, Hours						
A	13.5	11.7	10.1	12.6	11.7	11.6
B	12.6	10.4	10.9	12.2	10.7	9.4
C	11.0	12.9	9.8	12.9	11.6	10.3
D	13.3	12.7	9.2	13.0	11.6	10.3
SRT, Days						
A	13.0	9.6	8.7	6.8	8.7	10.0
B	16.5	15.0	17.0	18.8	15.9	20.7
C	16.0	19.5	15.5	14.6	13.4	12.4
D	21.0	29.4	12.3	14.4	14.2	12.2
SLUDGE VOLUME INDEX (SVI)						
A	130	92	89	96	118	136
B	185	169	108	154	168	171
C	228	238	220	205	107	80
D	197	235	159	156	167	136

APPENDIX TABLE D-1 (PART 1)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
MLSS, mg/L						
A	2,586	2,666	2,650	2,641	2,613	2,617
B	2,669	2,686	2,198	2,614	2,629	2,601
C	2,628	2,738	2,760	2,702	2,656	2,689
D	2,634	2,532	2,634	2,599	2,509	2,607
MLVSS, mg/l						
A	2,086	2,167	2,110	2,115	2,086	2,063
B	2,006	1,997	1,720	1,918	1,917	1,851
C	2,135	2,192	2,197	2,166	2,075	2,082
D	2,065	2,027	2,103	2,036	1,987	2,030
BOD, mg/L						
Raw Sewage	128	137	111	139	127	112
Primary Effluent						
A & B	110	108	76	106	102	95
C & D	123	125	96	117	116	105
Secondary Effluent						
A & B	8	9	14	6	6	5
C & D	5	6	8	3	4	4
PERCENT REMOVAL						
A & B	93.8	93.4	87.4	95.7	96.9	95.5
C & D	96.1	95.6	92.8	97.8	96.9	96.4
Suspended Solids, mg/L						
Raw Sewage	71	95	85	109	111	84
Primary Effluent						
A & B	68	65	50	72	67	65
C & D	65	81	64	77	91	75
PERCENT REMOVAL						
A & B	4.2	31.6	41.2	33.9	39.6	22.6
C & D	8.5	16.7	24.7	29.4	18.0	10.7
Secondary Effluent						
A & B	10	10	14	7	8	9
C & D	8	8	9	6	6	6
PERCENT REMOVAL						
A & B	85.9	89.5	83.5	93.6	92.8	89.3
C & D	88.7	91.6	89.4	96.3	94.6	92.9

APPENDIX TABLE D-1 (PART 1)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
NH4-N, mg/L						
Raw Sewage	18.5	16.0	13.7	19.6	18.9	18.5
Primary Effluent						
A & B	16.2	14.1	11.4	16.2	15.0	14.2
C & D	18.1	15.3	12.3	18.3	18.4	18.2
Secondary Effluent						
A & B	0.6	0.5	0.7	0.6	0.8	0.4
C & D	0.3	0.1	0.3	0.1	0.2	0.2
PERCENT REMOVAL						
A & B	96.8	96.9	94.9	96.9	95.8	97.8
C & D	98.4	99.4	97.8	99.5	98.9	98.9
RETURNED & WASTED SLUDGE						
Flow Rate Returned, mgd						
A	0.74	0.95	1.11	0.82	0.90	0.89
B	1.46	1.88	1.89	1.50	1.74	1.93
C	1.65	1.64	1.80	1.39	1.61	1.75
D	1.35	1.53	2.05	1.39	1.61	1.73
Flow Rate Returned, cu.m/d						
A	2,801	3,596	4,201	3,104	3,407	3,369
B	5,526	7,116	7,154	5,678	6,586	7,305
C	6,245	6,207	6,813	5,261	6,094	6,624
D	5,110	5,791	7,759	5,261	6,094	6,548
Flow Rate Wasted, mgd						
A	0.028	0.036	0.033	0.041	0.036	0.031
B	0.037	0.036	0.012	0.028	0.032	0.025
C	0.031	0.030	0.032	0.030	0.033	0.034
D	0.022	0.023	0.030	0.025	0.026	0.030
Flow Rate Wasted, cu.m/d						
A	106	136	125	155	136	117
B	140	136	45	106	121	95
C	117	114	121	114	125	129
D	83	87	114	95	98	114

APPENDIX TABLE D-1 (PART 1)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
Flow Rate Returned, mgd						
A & B	2.20	2.83	3.00	2.32	2.64	2.82
C & D	3.00	3.17	3.85	2.78	3.22	3.48
Flow Rate Returned, cu.m/d						
A & B	8,327	10,712	11,355	8,781	9,992	10,674
C & D	11,355	11,998	14,572	10,522	12,188	13,172
Flow Rate Wasted, mgd						
A & B	0.065	0.072	0.045	0.069	0.068	0.056
C & D	0.053	0.053	0.062	0.055	0.059	0.064
Flow Rate Wasted, cu.m/d						
A & B	246	273	170	261	257	212
C & D	201	201	235	208	223	242
Suspended Solids, mg/l						
A	4,242	5,030	5,612	5,571	5,158	4,984
B	5,120	5,254	4,978	5,487	5,201	5,213
C	6,046	6,153	6,505	6,551	6,354	6,879
D	7,036	6,836	7,713	7,522	7,377	8,067
Volalile Suspended Solids, mg/l						
A	3,508	4,215	4,620	4,485	4,223	3,912
B	4,154	4,391	3,902	4,582	4,239	4,224
C	4,933	4,789	5,300	5,286	5,300	5,611
D	5,707	5,371	6,145	6,061	5,935	6,272
PRIMARY + WASTE ACTIVATED SLUDGE						
Sludge Flow Rate, gpd (From Holding Tank Levels)						
A	7,900	8,700	6,120	8,750	8,180	7,540
B	7,690	8,370	5,560	8,170	6,300	5,280
A & B	15,590	17,070	11,680	16,920	14,480	12,820
C & D	18,670	22,360	14,920	24,240	16,930	19,110
Sludge Flow Rate, cu.m/d (From Holding Tank Levels)						
A	30	33	23	33	31	29
B	29	32	21	31	24	20
C	59	65	44	64	55	49
D	71	85	56	92	64	72
Sludge Flow Rate, gpd (From Pump Strokes)						
A & B	18,800	19,800	15,200	16,100	12,800	10,200
C & D	18,900	22,600	15,400	24,900	19,700	19,100

APPENDIX TABLE D-1 (PART 1)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
Sludge Flow Rate, cu.m/d (From Pump Strokes)						
A & B	71	75	58	61	48	39
C & D	72	86	58	94	75	72
Total Solids, %						
A	2.69	2.77	3.27	3.02	2.86	2.86
B	2.80	3.02	3.20	3.13	3.07	3.30
A & B	2.74	2.89	3.24	3.07	2.95	3.04
C & D	2.54	2.55	3.11	2.84	3.05	3.39
Total Vol=tile Solids, %						
A	77.4	78.5	78.2	77.5	76.1	73.3
B	77.8	78.8	76.9	78.0	76.0	72.8
A & B	77.6	78.7	77.6	77.7	76.1	73.1
C & D	78.5	78.8	79.1	77.7	75.7	74.0
ANAEROBIC DIGESTER SLUDGE						
Sludge Feed Rate, gpd						
1	17,250	18,430	13,310	18,610	16,220	14,000
3	17,820	20,410	14,650	24,280	19,250	18,770
Sludge Feed Rate, cu.m/d						
1	65	70	50	70	61	53
3	67	77	55	92	73	71
Sludge Withdrawal Rate, gpd						
2	17,160	17,990	12,190	18,270	15,770	13,880
4	17,920	20,880	15,220	24,910	19,040	19,020
Sludge Withdrawal Rate, cu.m/d						
2	65	68	46	69	60	53
4	68	79	58	94	72	72
Sludge Recycle Rate: DIG # 4						
%	0.0	0.0	0.0	0.0	0.0	0.0
gpd	0	0	0	0	0	0
cu.m/d	0	0	0	0	0	0
Detention Time, Days						
1	8.8	8.2	11.3	8.1	9.3	10.8
2	8.8	8.4	12.4	8.3	9.6	10.9
3	8.8	7.6	10.6	6.4	8.1	8.3
4	8.7	7.5	10.2	6.3	8.2	8.2

APPENDIX TABLE D-1 (PART 1)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
Total Solids, %						
1-Feed	2.74	2.89	3.24	3.07	2.95	3.04
1-Draw	1.89	1.78	1.78	2.09	2.00	1.92
2-Feed	1.89	1.78	1.78	2.09	2.00	1.92
2-Draw	1.82	1.62	1.42	1.73	1.85	1.64
3-Feed	2.54	2.55	3.11	2.84	3.05	3.39
3-Draw	1.74	1.74	1.81	1.99	1.88	2.29
4-Feed	1.74	1.74	1.81	1.99	1.88	2.29
4-Draw	1.64	1.43	1.42	1.72	1.59	1.90
Total Volatile Solids,%						
1-Feed	77.6	78.7	77.6	77.7	76.1	73.1
1-Draw	65.7	68.5	67.0	67.3	66.8	65.8
2-Feed	65.7	68.5	67.0	67.3	66.8	65.8
2-Draw	63.1	65.4	64.5	64.9	65.3	64.0
3-Feed	78.5	78.8	79.1	77.7	75.7	74.0
3-Draw	66.6	71.9	67.2	68.6	66.7	64.8
4-Feed	66.6	71.9	67.2	68.6	66.7	64.8
4-Draw	60.5	63.7	62.8	64.3	63.3	60.4
Total Solids In, lb/d						
1 & 2	3,948	4,446	3,593	4,770	3,992	3,551
3 & 4	3,775	4,341	3,800	5,751	4,897	5,307
Total Solids In, kg/d						
1 & 2	1,791	2,017	1,630	2,164	1,811	1,611
3 & 4	1,712	1,969	1,724	2,609	2,221	2,407
Total Solids Withdrawn, lb/d						
1 & 2	2,605	2,431	1,444	2,636	2,433	1,898
3 & 4	2,451	2,490	1,802	3,573	2,525	3,014
Total Solids Withdrawn, kg/d						
1 & 2	1,181	1,103	655	1,196	1,104	861
3 & 4	1,112	1,130	818	1,621	1,145	1,367
Total Solids Recycled: DIG # 4						
%	0.0	0.0	0.0	0.0	0.0	0.0
lb/d	0	0	0	0	0	0
kg/d	0	0	0	0	0	0
Total Solids Destroyed, lb/d						
1 & 2	1,343	2,015	2,149	2,134	1,559	1,652
3 & 4	1,324	1,850	1,997	2,178	2,372	2,293
Total Solids Destroyed, kg/d						
1 & 2	609	916	975	968	707	750
3 & 4	601	839	906	988	1,076	1,040

APPENDIX TABLE D-1 (PART 1)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
Total Solids Destroyed, %						
1 & 2	34.0	45.3	59.8	44.7	39.1	46.5
3 & 4	35.1	42.6	52.6	37.9	48.4	43.2
Volatile Solids In, lb/d						
1 & 2	3,064	3,497	2,788	3,708	3,036	2,595
3 & 4	2,963	3,420	3,006	4,468	3,707	3,927
Volatile Solids In, kg/d						
1 & 2	1,390	1,586	1,264	1,682	1,377	1,177
3 & 4	1,344	1,551	1,363	2,027	1,681	1,781
Volatile Solids Withdrawn, lb/d						
1 & 2	1,644	1,590	931	1,711	1,589	1,215
3 & 4	1,483	1,586	1,132	2,298	1,598	1,820
Volatile Solids Withdrawn, kg/d						
1 & 2	746	721	422	776	721	551
3 & 4	673	720	513	1,042	725	826
Volatile Solids Recycled: DIG # 4						
%	0.0	0.0	0.0	0.0	0.0	0.0
lb/d	0	0	0	0	0	0
kg/d	0	0	0	0	0	0
Volatile Solids Destroyed, lb/d						
1 & 2	1,420	1,907	1,857	1,997	1,448	1,380
3 & 4	1,480	1,834	1,874	2,171	2,109	2,107
Volatile Solids Destroyed, kg/d						
1 & 2	644	865	842	906	657	626
3 & 4	672	832	850	985	956	956
Volatile Solids Destroyed, %						
1 & 2	46.4	54.5	66.6	53.9	47.7	53.2
3 & 4	50.2	53.6	62.3	48.6	56.9	53.6
Gas Volume From Digesters cu.ft/d						
1	18,983	20,014	17,056	20,046	17,244	15,899
2			987	1,992	1,360	1,234
3	12,958	13,797	14,053	15,033	13,685	14,279
4	1,991	1,008	989	1,022	1,402	1,426
Gas Volume From Digesters cu.m/d						
1	537.60	566.80	483.03	567.70	488.35	450.26
2			27.95	56.41	38.52	34.95
3	366.97	390.73	397.98	425.73	387.56	404.38
4	56.39	28.55	28.01	28.94	39.70	40.38

APPENDIX TABLE D-1 (PART 1)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
Gas Production, cu.ft/lbs VS						
1	14.8	12.0	10.8	12.8	13.5	14.0
2			3.5	4.6	8.1	5.0
3	10.5	11.1	9.6	9.2	8.0	9.1
4	8.0	1.7	2.4	1.9	3.6	2.7
Gas Production, cu.m/kg VS						
1	0.92	0.75	0.68	0.80	0.84	0.88
2			0.22	0.29	0.50	0.31
3	0.66	0.69	0.60	0.57	0.50	0.57
4	0.50	0.11	0.15	0.12	0.22	0.17
Volatile Solids Loading Rate lbs/(cu.ft*d)						
1	0.15	0.17	0.14	0.18	0.15	0.13
2	0.09	0.09	0.06	0.11	0.09	0.07
3	0.14	0.16	0.14	0.21	0.18	0.19
4	0.08	0.10	0.07	0.14	0.10	0.11
Volatile Solids Loading Rate kg/(cu.m*d)						
1	2.43	2.77	2.21	2.94	2.41	2.06
2	1.41	1.45	0.96	1.70	1.39	1.16
3	2.28	2.63	2.31	3.43	2.85	3.02
4	1.33	1.67	1.19	2.18	1.53	1.81
Volatile Solids In, lb/d						
1	3,064	3,497	2,788	3,708	3,036	2,595
2	1,777	1,829	1,212	2,143	1,757	1,462
3	2,963	3,420	3,006	4,468	3,707	3,927
4	1,732	2,179	1,544	2,836	1,991	2,354
Volatile Solids In, kg/d						
1	1,390	1,586	1,264	1,682	1,377	1,177
2	806	830	550	972	797	663
3	1,344	1,551	1,363	2,027	1,681	1,781
4	786	988	700	1,286	903	1,068
Volatile Solids Destroyed, lb/d						
1	1,287	1,668	1,575	1,565	1,279	1,132
2	134	240	281	432	168	247
3	1,231	1,242	1,462	1,632	1,716	1,573
4	249	592	412	538	393	533

APPENDIX TABLE D-1 (PART 1)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
Volatile Solids Destroyed, kg/d						
1	584	756	715	710	580	514
2	61	109	128	196	76	112
3	559	563	663	740	778	714
4	113	269	187	244	178	242
Volatile Solids Destroyed, %						
1	42.0	47.7	56.5	42.2	62.1	43.6
2	7.5	13.1	23.2	20.2	9.6	16.9
3	41.6	36.3	48.6	36.5	46.3	40.1
4	14.4	27.2	26.7	19.0	19.7	22.7
pH						
1-Feed	5.8	6.0	5.8	5.6	5.5	5.6
1-Draw	7.4	7.3	7.3	7.2	7.2	7.2
2-Feed	7.4	7.3	7.3	7.2	7.2	7.2
2-Draw	7.4	7.4	7.4	7.4	7.3	7.3
3-Feed	5.8	5.9	5.8	5.8	5.6	5.5
3-Draw	7.4	7.2	7.3	7.3	7.2	7.3
4-Feed	7.4	7.2	7.3	7.3	7.2	7.3
4-Draw	7.9	7.8	7.8	7.8	7.8	7.8
Alkalinity, mg/L						
1-Feed	1,095	1,244	1,079	960	951	807
1-Draw	2,699	2,732	2,628	2,414	2,208	2,288
2-Feed	2,699	2,732	2,628	2,414	2,208	2,288
2-Draw	3,069	2,940	2,831	2,770	2,534	2,664
3-Feed	887	790	801	884	811	838
3-Draw	2,644	2,650	2,386	2,159	2,096	2,465
4-Feed	2,644	2,650	2,386	2,159	2,096	2,465
4-Draw	3,241	2,905	2,824	2,721	2,315	2,426
Volatile Acids, mg/L						
1-Feed						
1-Draw	148	248	266	51	69	133
2-Feed	148	248	266	51	69	133
2-Draw	165	182	328	25	43	44
3-Feed						
3-Draw	115	341	195	24	39	48
4-Feed	115	341	195	24	39	48
4-Draw	323	385	364	194	263	178

APPENDIX TABLE D-1 (PART 1)

MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
NH4-N, mg/L						
1-Feed	196	207	166	216	180	264
1-Draw	546	543	572	630	480	517
2-Feed	546	543	572	630	480	517
2-Draw	640	603	648	682	567	628
3-Feed	181	158	165	186	140	188
3-Draw	584	535	573	616	454	611
4-Feed	584	535	573	616	454	611
4-Draw	751	634	689	788	657	798
TKN, mg/L						
1-Feed	1,414	1,446	1,388	1,508	1,341	1,403
1-Draw	1,461	1,432	1,375	1,559	1,415	1,393
2-Feed	1,461	1,432	1,375	1,559	1,415	1,393
2-Draw	1,453	1,399	1,411	1,688	1,404	1,370
3-Feed	1,333	1,364	1,528	1,580	1,337	1,640
3-Draw	1,444	1,298	1,430	1,702	1,309	1,660
4-Feed	1,444	1,298	1,430	1,702	1,309	1,660
4-Draw	1,446	1,295	1,298	1,719	1,328	1,544
Total COD, mg/L						
1-Feed	34,136	36,286	38,191	40,561	34,050	37,993
1-Draw	21,007	18,464	18,847	24,461	20,592	21,625
2=Feed	21,007	18,464	18,847	24,461	20,592	21,625
2-Draw	18,020	16,677	15,448	19,133	18,620	17,363
3-Feed	31,607	32,057	36,335	36,689	34,585	40,862
3-Draw	19,300	18,266	18,735	21,986	19,154	23,450
4-Feed	19,300	18,266	18,735	21,986	19,154	23,450
4-Draw	16,050	15,100	14,547	19,069	16,292	19,412
Soluble COD, mg/L						
1-Feed	3,401	3,833	3,353	3,897	3,609	3,328
1-Draw	293	389	317	296	255	352
2-Feed	293	389	317	296	255	352
2-Draw	256	262	270	264	225	243
3-Feed	2,869	2,709	3,010	3,189	2,539	3,558
3-Draw	259	269	249	248	219	246
4-Feed	259	269	249	248	219	246
4-Draw	832	894	806	906	845	807
REMOVAL Total COD, %						
1	38.5	49.1	50.7	39.7	39.5	43.1
2	16.2	9.7	18.0	21.8	9.6	19.7
3	38.9	43.0	48.4	40.1	44.6	42.6
4	16.8	17.3	22.4	13.3	16.9	17.2

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APPENDIX TABLE D-1 (PART 1)

MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
REMOVAL Total COD, %						
1 & 2	67.2	54.0	59.6	52.8	65.3	54.3
3 & 4	69.2	52.9	60.0	68.0	52.9	52.5
REMOVAL Soluble COD, %						
1	91.4	89.9	90.5	92.4	92.9	89.4
2	12.6	32.6	14.8	10.8	11.8	31.0
3	91.0	90.1	91.7	92.2	91.4	93.1
4	-221.2	-232.3	-223.7	-265.3	-285.8	-228.0
REMOVAL Soluble COD, %						
1 & 2	92.5	93.2	91.9	93.2	93.8	92.7
3 & 4	71.0	67.0	73.2	71.6	66.7	77.3
THEORETICAL GAS PRODUCTION cu.ft/d						
1	17,122	24,832	19,465	22,652	16,503	17,326
2	3,875	2,430	3,132	7,359	2,351	4,472
3	16,580	21,280	19,493	26,989	22,457	24,709
4	4,403	4,998	4,819	5,493	4,120	5,806
THEORETICAL GAS PRODUCTION cu.m/d						
1	484.90	703.25	551.25	641.50	467.37	490.63
2	109.74	68.83	88.71	208.42	66.58	126.66
3	469.56	602.65	552.05	764.33	635.99	699.75
4	124.69	141.54	136.47	155.57	116.67	164.44
MEASURED GAS/THEORETICAL GAS						
1	1.109	0.806	0.876	0.885	1.045	0.918
2			0.315	0.271	0.578	0.276
3	0.782	0.648	0.721	0.557	0.609	0.578
4	0.452	0.202	0.205	0.186	0.340	0.266
COD Destroyed, lb/d						
1	1,889	2,739	2,147	2,499	1,821	1,911
2	427	268	346	812	259	493
3	1,829	2,347	2,150	2,977	2,477	2,726
4	486	551	532	606	454	641

APPENDIX TABLE D-1 (PART 1)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
COD Destroyed, kg/d						
1	857	1,243	974	1,133	826	867
2	194	122	157	368	118	226
3	830	1,065	975	1,350	1,124	1,236
4	220	250	241	275	206	291
#VS DESTROYED/#COD DESTROYED						
1	0.681	0.609	0.734	0.626	0.703	0.593
2	0.312	0.894	0.814	0.533	0.649	0.502
3	0.673	0.529	0.680	0.548	0.692	0.577
4	0.513	1.074	0.775	0.889	0.865	0.833

APPENDIX TABLE D-1 (PART 2)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
RAW SEWAGE						
Flow Rate, mgd						
A	1.02	1.19	1.47	1.13	1.23	1.21
B	2.04	2.51	2.54	2.04	2.40	2.71
C	2.26	2.21	2.57	1.92	2.25	2.44
D	1.87	2.08	2.82	1.91	2.25	2.44
Flow Rate, cu.m/d						
A	3,861	4,504	5,564	4,277	4,656	4,580
B	7,721	9,500	9,614	7,721	9,084	10,257
C	8,554	8,365	9,727	7,267	8,516	9,235
D	7,078	7,873	10,674	7,229	8,516	9,235
Flow Rate, mgd						
A & B	3.06	3.70	4.01	3.17	3.63	3.92
C & D	4.12	4.29	5.39	3.83	4.50	4.88
Flow Rate, cu.m/d						
A & B	11,582	14,005	15,178	11,998	13,740	14,837
C & D	15,594	16,238	20,401	14,497	17,033	18,471
Suspended Solids, mg/l	71	95	85	109	111	84
Volatile Suspended Solids, mg/l	60	79	69	89	92	70
BOD, mg/l	128	137	111	139	127	112
NH4-N, mg/l	18.5	16.0	13.7	19.6	18.9	18.5
AERATION BATTERIES						
HRT, Hours						
A	13.5	11.7	10.1	12.6	11.7	11.6
B	12.6	10.4	10.9	12.2	10.7	9.4
C	11.0	12.9	9.8	12.9	11.6	10.3
D	13.3	12.7	9.2	13.0	11.6	10.3
SRT, Days						
A	13.0	9.6	8.7	6.8	8.7	10.0
B	14.5	15.0	17.0	18.8	15.9	20.7
C	16.0	19.5	15.5	14.6	13.4	12.4
D	21.0	29.4	12.3	14.4	14.2	12.2
SLUDGE VOLUME INDEX (SVI)						
A	130	92	89	96	118	136
B	185	149	108	154	168	121
C	228	238	220	205	107	80
D	197	235	159	156	147	134

APPENDIX TABLE D-1 (PART 2)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
MLSS, mg/L						
A	2,586	2,666	2,650	2,641	2,613	2,617
B	2,469	2,486	2,198	2,414	2,429	2,401
C	2,628	2,738	2,760	2,702	2,656	2,689
D	2,634	2,532	2,634	2,559	2,509	2,607
MLVSS, mg/l						
A	2,086	2,167	2,110	2,115	2,086	2,063
B	2,006	1,997	1,720	1,918	1,917	1,851
C	2,135	2,192	2,197	2,166	2,075	2,082
D	2,065	2,027	2,103	2,036	1,987	2,030
BOD, mg/L						
Raw Sewage	128	137	111	139	127	112
Primary Effluent						
A & B	110	108	76	106	102	95
C & D	123	125	96	117	116	105
Secondary Effluent						
A & B	8	9	14	6	4	5
C & D	5	6	8	3	4	4
PERCENT REMOVAL						
A & B	93.8	93.4	87.4	95.7	96.9	95.5
C & D	96.1	95.6	92.8	97.8	96.9	96.4
Suspended Solids, mg/L						
Raw Sewage	71	95	85	109	111	84
Primary Effluent						
A & B	68	65	50	72	67	65
C & D	65	81	64	77	91	75
PERCENT REMOVAL						
A & B	4.2	31.6	41.2	33.9	39.6	22.6
C & D	8.5	14.7	24.7	29.4	18.0	10.7
Secondary Effluent						
A & B	10	10	14	7	8	9
C & D	8	8	9	4	6	6
PERCENT REMOVAL						
A & B	85.9	89.5	83.5	93.6	92.8	89.3
C & D	88.7	91.6	89.4	96.3	94.6	92.9

APPENDIX TABLE D-1 (PART 2)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
NH4-N, mg/L						
Raw Sewage	18.5	16.0	13.7	19.6	18.9	18.5
Primary Effluent						
A & B	16.2	16.1	11.6	16.2	15.0	16.2
C & D	18.1	15.3	12.3	18.3	18.6	18.2
Secondary Effluent						
A & B	0.6	0.5	0.7	0.6	0.8	0.4
C & D	0.3	0.1	0.3	0.1	0.2	0.2
PERCENT REMOVAL						
A & B	96.8	96.9	94.9	96.9	95.8	97.8
C & D	98.4	99.4	97.8	99.5	98.9	98.9
RETURNED & WASTED SLUDGE						
Flow Rate Returned, mgd						
A	0.74	0.95	1.11	0.82	0.90	0.89
B	1.46	1.88	1.89	1.50	1.74	1.93
C	1.65	1.64	1.80	1.39	1.61	1.75
D	1.35	1.53	2.05	1.39	1.61	1.73
Flow Rate Returned, cu.m/d						
A	2,801	3,596	4,201	3,104	3,407	3,369
B	5,526	7,116	7,154	5,678	6,586	7,305
C	6,245	6,207	6,813	5,261	6,094	6,624
D	5,110	5,791	7,759	5,261	6,094	6,548
Flow Rate Wasted, mgd						
A	0.028	0.036	0.033	0.041	0.036	0.031
B	0.037	0.036	0.012	0.028	0.032	0.025
C	0.031	0.030	0.032	0.030	0.033	0.034
D	0.022	0.023	0.030	0.025	0.026	0.030
Flow Rate Wasted, cu.m/d						
A	106	136	125	155	136	117
B	140	136	45	106	121	95
C	117	114	121	114	125	129
D	83	87	114	95	98	114

APPENDIX TABLE D-1 (PART 2)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
Flow Rate Returned, mgd						
A & B	2.20	2.83	3.00	2.32	2.64	2.82
C & D	3.00	3.17	3.85	2.78	3.22	3.48
Flow Rate Returned, cu.m/d						
A & B	8,327	10,712	11,355	8,781	9,992	10,676
C & D	11,355	11,998	14,572	10,522	12,188	13,172
Flow Rate Wasted, mgd						
A & B	0.065	0.072	0.045	0.069	0.068	0.056
C & D	0.053	0.053	0.062	0.055	0.059	0.064
Flow Rate Wasted, cu.m/d						
A & B	246	273	170	261	257	212
C & D	201	201	235	208	223	242
Suspended Solids, mg/l						
A	4,242	5,030	5,612	5,571	5,158	4,984
B	5,120	5,254	4,978	5,487	5,201	5,213
C	6,046	6.153	6,505	6,551	6,354	6,879
D	7,036	6.836	7,713	7,522	7,377	8,067
Volatile Suspended Solids, mg/l						
A	3,508	4,215	4,620	4,485	4,223	3,912
B	4,154	4,391	3,902	4,582	4,239	4,224
C	4,933	4,789	5,300	5,286	5,300	5,611
D	5,707	5,371	6,165	6,061	5,935	6,272
PRIMARY + WASTE ACTIVATED SLUDGE						
Sludge Flow Rate, gpd (From Holding Tank Levels)						
A	7,900	8,700	6,120	8,750	8,180	7,540
B	7,690	8,370	5,560	8,170	6,300	5,280
A & B	15,590	17,070	11,680	16,920	14,480	12,820
C & D	18,670	22,360	16,920	24,240	16,930	19,110
Sludge Flow Rate, cu.m/d (From Holding Tank Levels)						
A	30	33	23	33	31	29
B	29	32	21	31	24	20
C	59	65	44	64	55	49
D	71	85	56	92	64	72
Sludge Flow Rate, gpd (From Pump Strokes)						
A & B	18,800	19,800	15,200	16,100	12,800	10,200
C & D	18,900	22,600	15,400	24,900	19,700	19,100

APPENDIX TABLE D-1 (PART 2)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
Sludge Flow Rate, cu.m/d (From Pump Strokes)						
A & B	71	75	58	61	48	39
C & D	72	86	58	94	75	72
Total Solids, %						
A	2.69	2.77	3.27	3.02	2.86	2.86
B	2.80	3.02	3.20	3.13	3.07	3.30
A & B	2.74	2.89	3.24	3.07	2.95	3.04
C & D	2.54	2.55	3.11	2.84	3.05	3.39
Total Volatile Solids, %						
A	77.4	78.5	78.2	77.5	76.1	73.3
B	77.8	78.8	76.9	78.0	76.0	72.8
A & B	77.6	78.7	77.6	77.7	76.1	73.1
C & D	78.5	78.8	79.1	77.7	75.7	74.0
ANAEROBIC DIGESTER SLUDGE						
Sludge Feed Rate, gpd						
1	17,250	18,430	13,310	18,610	16,220	14,000
3	17,820	20,410	14,650	24,280	19,250	18,770
Sludge Feed Rate, cu.m/d						
1	65	70	50	70	61	53
3	67	77	55	92	73	71
Sludge Withdrawal Rate, gpd						
2	17,160	17,990	12,190	18,270	15,770	13,880
4	17,920	20,880	15,220	24,910	19,040	19,020
Sludge Withdrawal Rate, cu.m/d						
2	65	68	46	69	60	53
4	68	79	58	94	72	72
Sludge Recycle Rate: DIG # 4						
%	0.0	0.0	0.0	0.0	0.0	0.0
gpd	0	0	0	0	0	0
cu.m/d	0	0	0	0	0	0
Detention Time, Days						
1	8.8	8.2	11.3	8.1	9.3	10.8
2	8.8	8.4	12.4	8.3	9.6	10.9
3	8.8	7.6	10.6	6.4	8.1	8.3
4	8.7	7.5	10.2	6.3	8.2	8.2

APPENDIX TABLE D-1 (PART 2)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
Total Solids, %						
1-Feed	2.74	2.89	3.24	3.07	2.95	3.04
1-Draw	1.89	1.78	1.78	2.09	2.00	1.92
2-Feed	1.89	1.78	1.78	2.09	2.00	1.92
2-Draw	1.82	1.62	1.42	1.73	1.85	1.64
3-Feed	2.54	2.55	3.11	2.84	3.05	3.39
3-Draw	1.74	1.74	1.81	1.99	1.88	2.29
4-Feed	1.74	1.74	1.81	1.99	1.88	2.29
4-Draw	1.64	1.43	1.42	1.72	1.59	1.90
Total Volatile Solids,%						
1-Feed	77.6	78.7	77.6	77.7	76.1	73.1
1-Draw	65.7	68.5	67.0	67.3	66.8	65.8
2-Feed	65.7	68.5	67.0	67.3	66.8	65.8
2-Draw	63.1	65.4	64.5	64.9	65.3	64.0
3-Feed	78.5	78.8	79.1	77.7	75.7	74.0
3-Draw	66.6	71.9	67.2	68.6	66.7	64.8
4-Feed	66.6	71.9	67.2	68.6	66.7	64.8
4-Draw	60.5	63.7	62.8	64.3	63.3	60.4
Total Solids In, lb/d						
1 & 2	3,948	4,446	3,593	4,770	3,992	3,551
3 & 4	3,775	4,341	3,800	5,751	4,897	5,307
Total Solids In, kg/d						
1 & 2	1,791	2,017	1,630	2,164	1,811	1,611
3 & 4	1,712	1,969	1,724	2,609	2,221	2,407
Total Solids Withdrawn, lb/d						
1 & 2	2,605	2,431	1,444	2,636	2,433	1,898
3 & 4	2,451	2,490	1,802	3,573	2,525	3,014
Total Solids Withdrawn, kg/d						
1 & 2	1,181	1,103	655	1,196	1,104	861
3 & 4	1,112	1,130	818	1,621	1,145	1,367
Total Solids Recycled: DIG # 4						
%	0.0	0.0	0.0	0.0	0.0	0.0
lb/d	0	0	0	0	0	0
kg/d	0	0	0	0	0	0
Total Solids Destroyed, lb/d						
1 & 2	1,343	2,015	2,149	2,134	1,559	1,652
3 & 4	1,324	1,850	1,997	2,178	2,372	2,293
Total Solids Destroyed, kg/d						
1 & 2	609	914	975	968	707	750
3 & 4	601	839	906	988	1,076	1,040

APPENDIX TABLE D-1 (PART 2)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
Total Solids Destroyed, %						
1 & 2	34.0	45.3	59.8	44.7	39.1	46.5
3 & 4	35.1	42.6	52.6	37.9	48.4	43.2
Volatile Solids In, lb/d						
1 & 2	3,064	3,497	2,788	3,708	3,036	2,595
3 & 4	2,963	3,420	3,006	4,468	3,707	3,927
Volatile Solids In, kg/d						
1 & 2	1,390	1,586	1,264	1,682	1,377	1,177
3 & 4	1,344	1,551	1,363	2,027	1,681	1,781
Volatile Solids Withdrawn, lb/d						
1 & 2	1,644	1,590	931	1,711	1,589	1,215
3 & 4	1,483	1,586	1,132	2,298	1,598	1,820
Volatile Solids Withdrawn, kg/d						
1 & 2	746	721	422	776	721	551
3 & 4	673	720	513	1,042	725	826
Volatile Solids Recycled: DIG # 4						
%	0.0	0.0	0.0	0.0	0.0	0.0
lb/d	0	0	0	0	0	0
kg/d	0	0	0	0	0	0
Volatile Solids Destroyed, lb/d						
1 & 2	1,420	1,907	1,857	1,997	1,448	1,380
3 & 4	1,480	1,834	1,874	2,171	2,109	2,107
Volatile Solids Destroyed, kg/d						
1 & 2	644	865	842	906	657	626
3 & 4	672	832	850	985	956	956
Volatile Solids Destroyed, %						
1 & 2	46.4	54.5	66.6	53.9	47.7	53.2
3 & 4	50.2	53.6	62.3	48.6	56.9	53.6
Gas Volume From Digesters						
cu.ft/d						
1	18,983	20,014	17,056	20,046	17,244	15,899
2			987	1,992	1,360	1,234
3	12,958	13,797	14,053	15,033	13,685	14,279
4	1,991	1,008	989	1,022	1,402	1,426
Gas Volume From Digesters						
cu.m/d						
1	537.60	566.80	483.03	567.70	488.35	450.26
2			27.95	56.41	38.52	34.95
3	366.97	390.73	397.98	425.73	387.56	404.38
4	56.39	28.55	28.01	28.94	39.70	40.38

APPENDIX TABLE D-1 (PART 2)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
Gas Production, cu.ft/lbs VS						
1	14.8	12.0	10.8	12.8	13.5	14.0
2			3.5	4.6	8.1	5.0
3	10.5	11.1	9.6	9.2	8.0	9.1
4	8.0	1.7	2.4	1.9	3.6	2.7
Gas Production, cu.m/kg VS						
1	0.92	0.75	0.68	0.80	0.84	0.88
2			0.22	0.29	0.50	0.31
3	0.66	0.69	0.60	0.57	0.50	0.57
4	0.50	0.11	0.15	0.12	0.22	0.17
Volatile Solids Loading Rate lbs/(cu.ft*d)						
1	0.15	0.17	0.14	0.18	0.15	0.13
2	0.09	0.09	0.06	0.11	0.09	0.07
3	0.14	0.16	0.14	0.21	0.18	0.19
4	0.08	0.10	0.07	0.14	0.10	0.11
Volatile Solids Loading Rate kg/(cu.m*d)						
1	2.43	2.77	2.21	2.94	2.41	2.06
2	1.41	1.45	0.96	1.70	1.39	1.16
3	2.28	2.63	2.31	3.43	2.85	3.02
4	1.33	1.67	1.19	2.18	1.53	1.81
Volatile Solids In, lb/d						
1	3,064	3,497	2,788	3,708	3,036	2,595
2	1,777	1,829	1,212	2,143	1,757	1,462
3	2,963	3,420	3,006	4,468	3,707	3,927
4	1,732	2,179	1,544	2,836	1,991	2,354
Volatile Solids In, kg/d						
1	1,390	1,586	1,264	1,682	1,377	1,177
2	806	830	550	972	797	663
3	1,344	1,551	1,363	2,027	1,681	1,781
4	786	988	700	1,286	903	1,068
Volatile Solids Destroyed, lb/d						
1	1,287	1,668	1,575	1,565	1,279	1,132
2	134	240	281	432	168	247
3	1,231	1,242	1,462	1,632	1,716	1,573
4	249	592	412	538	393	533

APPENDIX TABLE D-1 (PART 2)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
Volatile Solids Destroyed, kg/d						
1	584	756	715	710	580	514
2	61	109	128	196	76	112
3	559	563	663	740	778	714
4	113	269	187	244	178	242
Volatile Solids Destroyed, %						
1	42.0	47.7	56.5	42.2	42.1	43.6
2	7.5	13.1	23.2	20.2	9.6	16.9
3	41.6	36.3	48.6	36.5	46.3	40.1
4	14.4	27.2	26.7	19.0	19.7	22.7
pH						
1-Feed	5.8	6.0	5.8	5.6	5.5	5.6
1-Draw	7.4	7.3	7.3	7.2	7.2	7.2
2-Feed	7.4	7.3	7.3	7.2	7.2	7.2
2-Draw	7.4	7.4	7.4	7.4	7.3	7.3
3-Feed	5.8	5.9	5.8	5.8	5.6	5.5
3-Draw	7.4	7.2	7.3	7.3	7.2	7.3
4-Feed	7.4	7.2	7.3	7.3	7.2	7.3
4-Draw	7.9	7.8	7.8	7.8	7.8	7.8
Alkalinity, mg/L						
1-Feed	1,095	1,244	1,079	960	951	807
1-Draw	2,699	2,732	2,628	2,414	2,208	2,288
2-Feed	2,699	2,732	2,628	2,414	2,208	2,288
2-Draw	3,069	2,940	2,831	2,770	2,534	2,664
3-Feed	887	790	801	884	811	838
3-Draw	2,644	2,650	2,386	2,159	2,096	2,465
4-Feed	2,644	2,650	2,386	2,159	2,096	2,465
4-Draw	3,241	2,905	2,824	2,721	2,315	2,426
Volatile Acids, mg/L						
1-Feed						
1-Draw	148	248	266	51	69	133
2-Feed	148	248	266	51	69	133
2-Draw	165	182	328	25	43	44
3-Feed						
3-Draw	115	341	195	24	39	48
4-Feed	115	341	195	24	39	48
4-Draw	323	385	364	194	243	178

APPENDIX TABLE D-1 (PART 2)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
NH4-N, mg/L						
1-Feed	196	207	166	214	180	244
1-Draw	546	543	572	630	480	517
2-Feed	546	543	572	630	480	517
2-Draw	640	603	648	682	567	628
3-Feed	181	158	165	186	140	188
3-Draw	584	535	573	616	454	611
4-Feed	584	535	573	616	454	611
4-Draw	751	634	689	788	657	798
TKN, mg/L						
1-Feed	1,414	1,446	1,388	1,508	1,341	1,403
1-Draw	1,461	1,432	1,375	1,559	1,415	1,393
2-Feed	1,461	1,432	1,375	1,559	1,415	1,393
2-Draw	1,453	1,399	1,411	1,688	1,404	1,370
3-Feed	1,333	1,364	1,528	1,580	1,337	1,640
3-Draw	1,444	1,298	1,430	1,702	1,309	1,660
4-Feed	1,444	1,298	1,430	1,702	1,309	1,660
4-Draw	1,446	1,295	1,298	1,719	1,328	1,544
Total COD, mg/L						
1-Feed	34,136	36,286	38,191	40,561	34,050	37,993
1-Draw	21,007	18,464	18,847	24,461	20,592	21,625
2=Feed	21,007	18,464	18,847	24,461	20,592	21,625
2-Draw	18,020	16,677	15,448	19,133	18,620	17,363
3-Feed	31,607	32,057	36,335	36,689	34,585	40,862
3-Draw	19,300	18,266	18,735	21,986	19,154	23,450
4-Feed	19,300	18,266	18,735	21,986	19,154	23,450
4-Draw	16,050	15,100	14,547	19,069	16,292	19,412
Soluble COD, mg/L						
1-Feed	3,401	3,833	3,353	3,897	3,609	3,328
1-Draw	293	389	317	296	255	352
2-Feed	293	389	317	296	255	352
2-Draw	256	262	270	264	225	243
3-Feed	2,869	2,709	3,010	3,189	2,539	3,558
3-Draw	259	269	249	248	219	246
4-Feed	259	269	249	248	219	246
4-Draw	832	894	806	906	845	807
REMOVAL Total COD, %						
1	38.5	49.1	50.7	39.7	39.5	43.1
2	14.2	9.7	18.0	21.8	9.6	19.7
3	38.9	43.0	48.4	40.1	44.6	42.6
4	16.8	17.3	22.4	13.3	14.9	17.2

APPENDIX TABLE D-1 (PART 2)

MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
REMOVAL Total COD, %						
1 & 2	47.2	54.0	59.6	52.8	45.3	54.3
3 & 4	49.2	52.0	60.0	48.0	52.9	52.5
REMOVAL Soluble COD, %						
1	91.4	89.9	90.5	92.4	92.9	89.4
2	12.6	32.6	14.8	10.8	11.8	31.0
3	91.0	90.1	91.7	92.2	91.4	93.1
4	-221.2	-232.3	-223.7	-265.3	-285.8	-228.0
REMOVAL Soluble COD, %						
1 & 2	92.5	93.2	91.9	93.2	93.8	92.7
3 & 4	71.0	67.0	73.2	71.6	66.7	77.3
THEORETICAL GAS PRODUCTION cu.ft/d						
1	17,122	24,832	19,465	22,652	16,503	17,324
2	3,875	2,430	3,132	7,359	2,351	4,472
3	16,580	21,280	19,493	26,989	22,457	24,709
4	4,403	4,998	4,819	5,493	4,120	5,806
THEORETICAL GAS PRODUCTION cu.m/d						
1	484.90	703.25	551.25	641.50	467.37	490.63
2	109.74	68.83	88.71	208.42	66.58	126.66
3	469.56	602.65	552.05	764.33	635.99	699.75
4	124.69	141.54	136.47	155.57	116.67	164.44
MEASURED GAS/THEORETICAL GAS						
1	1.109	0.806	0.876	0.885	1.045	0.918
2			0.315	0.271	0.578	0.276
3	0.782	0.648	0.721	0.557	0.609	0.578
4	0.452	0.202	0.205	0.186	0.340	0.246
COD Destroyed, lb/d						
1	1,889	2,739	2,147	2,499	1,821	1,911
2	427	268	346	812	259	493
3	1,829	2,347	2,150	2,977	2,477	2,726
4	486	551	532	606	454	641

APPENDIX TABLE D-1 (PART 2)
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 2

	1986					
	JAN	FEB	MAR	APR	MAY	JUN
COD Destroyed, kg/d						
1	857	1,243	974	1,133	826	867
2	194	122	157	368	118	224
3	830	1,065	975	1,350	1,124	1,236
4	220	250	241	275	206	291
#VS DESTROYED/#COD DESTROYED						
1	0.681	0.609	0.734	0.626	0.703	0.593
2	0.312	0.894	0.814	0.533	0.649	0.502
3	0.673	0.529	0.680	0.548	0.692	0.577
4	0.513	1.074	0.775	0.889	0.865	0.833

APPENDIX TABLE D-2

MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3a

	1987			
	MAR	APR	MAY	JUN
RAW SEWAGE				
Flow Rate, mgd				
A	1.38	1.25	1.23	1.09
B	2.57	2.88	2.36	2.00
C	2.65	2.79	2.40	2.07
D	2.51	2.64	2.27	1.91
Flow Rate, cu.m/d				
A	5,223	4,731	4,656	4,126
B	9,727	10,901	8,933	7,570
C	10,030	10,560	9,084	7,835
D	9,500	9,992	8,592	7,229
Flow Rate, mgd				
A & B	3.95	4.13	3.59	3.09
C & D	6.15	5.43	4.67	3.98
Flow Rate, cu.m/d				
A & B	14,951	15,632	13,588	11,696
C & D	23,278	20,553	17,676	15,064
Suspended Solids, mg/l	88	93	91	89
Volatile Suspended Solids, mg/l	72	76	74	76
BOD, mg/l	116	123	112	126
NH4-N, mg/l	13.7	14.2	17.0	19.5
AERATION BATTERIES				
HRT, Hours				
A	10.1	11.2	11.5	12.8
B	9.7	9.4	11.0	12.4
C	9.5	9.3	10.6	12.0
D	10.0	9.8	11.1	13.0
SRT, Days				
A	8.2	12.0	8.9	9.0
B	12.1	15.0	16.8	21.2
C	12.7	13.7	13.0	16.3
D	12.3	14.4	12.3	10.1
SLUDGE VOLUME INDEX (SVI)				
A	84	104	86	96
B	161	92	148	109
C	89	87	86	81
D	124	115	98	97

APPENDIX TABLE D-2
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3a

	1987			
	MAR	APR	MAY	JUN
MLSS, mg/L				
A	2,871	2,870	3,034	2,953
B	2,727	2,680	2,807	2,681
C	2,919	3,007	3,008	2,898
D	2,840	2,927	2,965	2,852
MLVSS, mg/l				
A	2,320	2,305	2,434	2,385
B	2,191	2,124	2,219	2,118
C	2,329	2,363	2,358	2,277
D	2,252	2,301	2,333	2,226
BOD, mg/L				
Raw Sewage	116	123	112	126
Primary Effluent				
A & B	81	68	72	81
C & D	95	84	91	106
Secondary Effluent				
A & B	6	6	4	4
C & D	6	6	3	3
PERCENT REMOVAL				
A & B	94.8	95.1	96.4	96.8
C & D	94.8	95.1	97.3	97.6
Suspended Solids, mg/L				
Raw Sewage	88	93	91	89
Primary Effluent				
A & B	48	51	47	52
C & D	63	67	60	64
PERCENT REMOVAL				
A & B	75.6	70.9	75.6	73.4
C & D	61.9	62.2	69.1	69.1
Secondary Effluent				
A & B	10	8	6	6
C & D	8	8	4	4
PERCENT REMOVAL				
A & B	88.6	91.4	93.4	93.3
C & D	90.9	91.4	95.6	95.5

APPENDIX TABLE D-2
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3a

	1987			
	MAR	APR	MAY	JUN
NH4-N, mg/L				
Raw Sewage	13.7	14.2	17.0	19.5
Primary Effluent				
A & B	10.7	11.1	12.5	15.2
C & D	13.4	12.6	15.8	18.2
Secondary Effluent				
A & B	0.2	1.0	0.4	0.7
C & D	0.2	0.7	0.3	0.3
PERCENT REMOVAL				
A & B	98.5	93.0	97.6	96.4
C & D	98.5	95.1	98.2	98.5
RETURNED & WASTED SLUDGE				
Flow Rate Returned, mgd				
A	1.02	0.92	0.89	0.78
B	1.86	2.04	1.70	1.46
C	1.90	1.95	1.71	1.48
D	1.81	1.87	1.65	1.39
Flow Rate Returned, cu.m/d				
A	3,861	3,482	3,369	2,952
B	7,040	7,721	6,435	5,526
C	7,192	7,381	6,472	5,602
D	6,851	7,078	6,245	5,261
Flow Rate Wasted, mgd				
A	0.037	0.027	0.033	0.035
B	0.040	0.034	0.029	0.024
C	0.034	0.033	0.033	0.028
D	0.031	0.028	0.029	0.039
Flow Rate Wasted, cu.m/d				
A	140	102	125	132
B	151	129	110	91
C	129	125	125	106
D	117	106	110	148

APPENDIX TABLE D-2
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3a

	1987			
	MAR	APR	MAY	JUN
Flow Rate Returned, mgd				
A & B	2.88	2.96	2.59	2.24
C & D	3.71	3.82	3.36	2.87
Flow Rate Returned, cu.m/d				
A & B	10,901	11,204	9,803	8,478
C & D	14,042	14,459	12,718	10,863
Flow Rate Wasted, mgd				
A & B	0.077	0.061	0.062	0.059
C & D	0.065	0.061	0.062	0.067
Flow Rate Wasted, cu.m/d				
A & B	291	231	235	223
C & D	246	231	235	254
Suspended Solids, mg/l				
A	5,628	5,596	5,913	5,461
B	5,942	5,856	6,291	6,242
C	7,055	7,133	7,251	5,030
D	7,925	8,350	8,784	8,765
Volalile Suspended Solids, mg/l				
A	4,554	4,542	4,850	4,340
B	5,043	4,590	5,101	4,616
C	5,597	5,499	5,801	5,299
D	6,240	6,532	7,226	6,696
PRIMARY + WASTE ACTIVATED SLUDGE				
Sludge Flow Rate, gpd (From Holding Tank Levels)				
A	7,090	5,750	9,100	7,340
B	6,370	3,140	7,680	4,020
A & B	13,460	8,890	16,780	11,360
C & D	16,000	17,100	19,400	17,900
Sludge Flow Rate, cu.m/d (From Holding Tank Levels)				
A	27	22	34	28
B	24	12	29	15
C	51	34	64	43
D	61	65	73	68
Sludge Flow Rate, gpd (From Pump Strokes)				
A & B	14,800	10,800	18,100	11,300
C & D	17,000	17,500	20,500	18,000

APPENDIX TABLE D-2
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3a

	1987			
	MAR	APR	MAY	JUN
Sludge Flow Rate, cu.m/d (From Pump Strokes)				
A & B	56	41	69	43
C & D	64	66	78	68
Total Solids, %				
A	3.19	3.30	2.70	2.44
B	3.83	4.48	3.36	2.95
A & B	3.49	3.72	3.00	2.62
C & D	3.67	3.60	3.18	3.13
Total Volatile Solids, %				
A	79.6	78.9	77.7	77.2
B	79.8	78.8	78.0	76.0
A & B	79.7	78.9	77.9	76.7
C & D	79.7	77.7	77.0	75.9
ANAEROBIC DIGESTER SLUDGE				
Sludge Feed Rate, gpd				
1	13,740	9,200	17,000	11,800
3	19,130	19,300	21,700	19,300
Sludge Feed Rate, cu.m/d				
1	52	35	64	45
3	72	73	82	73
Sludge Withdrawal Rate, gpd				
2	14,550	9,100	16,400	11,300
4	20,360	20,270	23,280	20,580
Sludge Withdrawal Rate, cu.m/d				
2	55	34	62	43
4	77	77	88	78
Sludge Recycle Rate: DIG # 4				
%	12.4	13.7	12.4	14.0
gpd	2,520	2,770	2,880	2,880
cu.m/d	10	10	11	11
Detention Time, Days				
1	11.0	16.4	8.9	12.8
2	10.4	16.6	9.2	13.4
3	8.2	8.1	7.2	8.1
4	7.7	7.7	6.7	7.6

APPENDIX TABLE D-2
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3a

	1987			
	MAR	APR	MAY	JUN
Total Solids, %				
1-Feed	3.49	3.72	3.00	2.62
1-Draw	2.07	2.05	1.99	1.61
2-Feed	2.07	2.05	1.99	1.61
2-Draw	1.90	1.81	1.82	1.42
3-Feed	3.67	3.60	3.18	3.13
3-Draw	2.08	2.10	2.08	1.92
4-Feed	2.08	2.10	2.08	1.92
4-Draw	1.69	1.74	1.82	1.63
Total Volatile Solids,%				
1-Feed	79.7	78.9	77.9	76.7
1-Draw	70.1	69.5	68.7	68.0
2-Feed	70.1	69.5	68.7	68.0
2-Draw	67.8	68.3	67.1	66.3
3-Feed	79.7	77.7	77.0	75.9
3-Draw	70.0	69.3	67.5	66.5
4-Feed	70.0	69.3	67.5	66.5
4-Draw	65.0	65.2	63.7	62.7
Total Solids In, lb/d				
1 & 2	4,003	2,852	4,256	2,579
3 & 4	5,855	5,795	5,755	5,038
Total Solids In, kg/d				
1 & 2	1,816	1,294	1,931	1,170
3 & 4	2,656	2,628	2,611	2,285
Total Solids Withdrawn, lb/d				
1 & 2	2,306	1,374	2,489	1,338
3 & 4	2,870	2,942	3,534	2,798
Total Solids Withdrawn, kg/d				
1 & 2	1,046	623	1,129	607
3 & 4	1,302	1,334	1,603	1,269
Total Solids Recycled: DIG # 4				
%	12.4	13.7	12.4	14.0
lb/d	355	402	437	392
kg/d	161	182	198	178
Total Solids Destroyed, lb/d				
1 & 2	1,697	1,478	1,767	1,241
3 & 4	2,986	2,853	2,221	2,240
Total Solids Destroyed, kg/d				
1 & 2	770	670	802	563
3 & 4	1,354	1,294	1,008	1,016

APPENDIX TABLE D-2
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3a

	1987			
	MAR	APR	MAY	JUN
Total Solids Destroyed, %				
1 & 2	42.4	51.8	41.5	48.1
3 & 4	51.0	49.2	38.6	44.5
Volatile Solids In, lb/d				
1 & 2	3,190	2,249	3,314	1,979
3 & 4	4,667	4,502	4,431	3,824
Volatile Solids In, kg/d				
1 & 2	1,447	1,020	1,503	897
3 & 4	2,117	2,042	2,010	1,735
Volatile Solids Withdrawn, lb/d				
1 & 2	1,563	938	1,670	887
3 & 4	1,865	1,918	2,251	1,754
Volatile Solids Withdrawn, kg/d				
1 & 2	709	426	758	402
3 & 4	846	870	1,021	796
Volatile Solids Recycled: DIG # 4				
%	12.4	13.7	12.4	14.0
lb/d	231	262	278	245
kg/d	105	119	126	111
Volatile Solids Destroyed, lb/d				
1 & 2	1,627	1,311	1,643	1,091
3 & 4	2,801	2,585	2,181	2,070
Volatile Solids Destroyed, kg/d				
1 & 2	738	595	745	495
3 & 4	1,271	1,172	989	939
Volatile Solids Destroyed, %				
1 & 2	51.0	58.3	49.6	55.2
3 & 4	60.0	57.4	49.2	54.1
Gas Volume From Digesters cu.ft/d				
1	17,350	15,400	18,160	11,380
2	3,630	2,490	3,540	2,590
3	27,110	27,370	27,730	22,180
4	8,100	6,790	6,750	5,880
Gas Volume From Digesters cu.m/d				
1	491.35	436.13	514.29	322.28
2	102.80	70.52	100.25	73.35
3	767.76	775.12	785.31	628.14
4	229.39	192.29	191.16	166.52

APPENDIX TABLE D-2
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3a

	1987			
	MAR	APR	MAY	JUN
Gas Production, cu.ft/lbs VS				
1	12.1	13.2	12.6	12.0
2	18.4	17.4	17.7	17.9
3	12.4	13.4	16.3	13.6
4	13.3	12.5	14.2	13.4
Gas Production, cu.m/kg VS				
1	0.76	0.82	0.79	0.75
2	1.15	1.09	1.11	1.12
3	0.77	0.84	1.02	0.85
4	0.83	0.78	0.89	0.84
Volatile Solids Loading Rate lbs/(cu.ft*d)				
1	0.16	0.11	0.16	0.10
2	0.09	0.05	0.09	0.05
3	0.22	0.22	0.21	0.18
4	0.12	0.12	0.13	0.11
Volatile Solids Loading Rate kg/(cu.m*d)				
1	2.53	1.78	2.63	1.57
2	1.40	0.86	1.48	0.82
3	3.58	3.46	3.40	2.94
4	1.90	1.89	2.09	1.68
Volatile Solids In, lb/d				
1	3,190	2,249	3,314	1,979
2	1,761	1,081	1,870	1,032
3	4,667	4,502	4,431	3,824
4	2,472	2,460	2,726	2,191
Volatile Solids In, kg/d				
1	1,447	1,020	1,503	897
2	799	490	848	468
3	2,117	2,042	2,010	1,735
4	1,121	1,116	1,236	994
Volatile Solids Destroyed, lb/d				
1	1,429	1,168	1,444	947
2	198	143	200	145
3	2,194	2,042	1,705	1,632
4	607	542	475	437

APPENDIX TABLE D-2

MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3a

	1987			
	MAR	APR	MAY	JUN
Volatile Solids Destroyed, kg/d				
1	648	530	655	429
2	90	65	91	66
3	995	926	774	740
4	275	246	215	198
Volatile Solids Destroyed, %				
1	44.8	51.9	43.6	47.9
2	11.2	13.2	10.7	14.0
3	47.0	45.4	38.5	42.7
4	24.6	22.0	17.4	20.0
pH				
1-Feed	5.7	5.5	5.5	5.9
1-Draw	7.3	7.4	7.3	7.3
2-Feed	7.3	7.4	7.3	7.3
2-Draw	7.4	7.5	7.4	7.4
3-Feed	5.7	5.7	5.6	5.4
3-Draw	7.3	7.3	7.3	7.3
4-Feed	7.3	7.3	7.3	7.3
4-Draw	7.9	7.9	7.9	7.8
Alkalinity, mg/L				
1-Feed	816	838	724	651
1-Draw	2,509	2,597	2,564	2,033
2-Feed	2,509	2,597	2,564	2,033
2-Draw	2,657	2,848	2,790	2,239
3-Feed	804	743	877	669
3-Draw	2,099	2,307	2,521	2,123
4-Feed	2,099	2,307	2,521	2,123
4-Draw	2,653	2,618	2,890	2,239
Volatile Acids, mg/L				
1-Feed	1,852	1,980	1,750	1,491
1-Draw	71	36	49	27
2-Feed	71	36	49	27
2-Draw	33	27	22	24
3-Feed	1,612	1,644	877	1,761
3-Draw	43	33	2,521	24
4-Feed	43	33	26	24
4-Draw	185	203	209	176

APPENDIX TABLE D-2
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3a

	1987			
	MAR	APR	MAY	JUN
NH4-N, mg/L				
1-Feed	176	157	157	132
1-Draw	557	666	662	469
2-Feed	557	662	662	469
2-Draw	673	731	710	506
3-Feed	163	165	204	182
3-Draw	516	565	584	479
4-Feed	516	565	584	479
4-Draw	620	765	827	656
TKN, mg/L				
1-Feed	1,809	1,668	1,668	1,363
1-Draw	1,749	1,777	1,590	1,303
2-Feed	1,749	1,590	1,590	1,303
2-Draw	1,747	1,571	1,615	1,275
3-Feed	1,950	1,784	1,718	1,574
3-Draw	1,689	1,725	1,615	1,436
4-Feed	1,689	1,725	1,615	1,436
4-Draw	1,554	1,547	1,589	1,437
Total COD, mg/L				
1-Feed	42,038	47,523	39,033	33,567
1-Draw	25,678	23,242	20,488	17,723
2=Feed	25,678	23,242	20,488	17,723
2-Draw	21,406	19,824	17,731	14,874
3-Feed	46,367	42,130	40,844	38,706
3-Draw	24,893	23,258	23,770	20,747
4-Feed	24,893	23,258	23,770	20,747
4-Draw	19,052	18,518	19,365	16,986
Soluble COD, mg/L				
1-Feed	3,064	3,095	3,095	2,383
1-Draw	377	296	339	295
2-Feed	377	339	339	395
2-Draw	327	299	290	265
3-Feed	2,603	2,784	2,533	3,093
3-Draw	327	274	263	248
4-Feed	327	274	263	248
4-Draw	1,145	868	844	917
REMOVAL Total COD, %				
1	38.9	51.1	47.5	47.2
2	16.6	14.7	13.5	16.1
3	46.3	44.8	41.8	46.4
4	23.5	20.4	18.5	18.1

APPENDIX TABLE D-2
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3a

	1987			
	MAR	APR	MAY	JUN
REMOVAL Total COD, %				
1 & 2	49.1	58.3	54.6	55.7
3 & 4	58.9	56.0	52.6	56.1
REMOVAL Soluble COD, %				
1	87.7	90.4	89.0	87.6
2	13.3	11.8	14.5	32.9
3	87.4	90.2	89.6	92.0
4	-250.2	-216.8	-220.9	-269.8
REMOVAL Soluble COD, %				
1 & 2	89.3	90.3	90.6	88.9
3 & 4	56.0	68.8	66.7	70.4
THEORETICAL GAS PRODUCTION cu.ft/d				
1	16,994	16,888	23,835	14,135
2	4,699	2,352	3,418	2,434
3	31,057	27,537	28,011	26,204
4	8,991	7,264	7,753	5,852
THEORETICAL GAS PRODUCTION cu.m/d				
1	481.28	478.28	675.00	400.29
2	133.08	66.59	96.81	68.93
3	879.54	779.83	793.27	742.11
4	254.62	205.71	219.56	165.72
MEASURED GAS/THEORETICAL GAS				
1	1.021	0.912	0.762	0.805
2	0.772	1.059	1.036	1.064
3	0.873	0.994	0.990	0.846
4	0.901	0.935	0.871	1.005
COD Destroyed, lb/d				
1	1,875	1,863	2,629	1,559
2	518	259	377	268
3	3,426	3,038	3,090	2,891
4	992	801	855	646

APPENDIX TABLE D-2
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3a

	1987			
	MAR	APR	MAY	JUN
COD Destroyed, kg/d				
1	850	845	1,193	707
2	235	118	171	122
3	1,554	1,378	1,402	1,311
4	450	363	388	293
#VS DESTROYED/#COD DESTROYED				
1	0.762	0.627	0.549	0.607
2	0.381	0.552	0.529	0.538
3	0.640	0.672	0.552	0.565
4	0.612	0.677	0.555	0.677

APPENDIX TABLE D-3

MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3b

	1987	
	AUG	SEP
RAW SEWAGE		
Flow Rate, mgd		
A	2.40	1.33
B	3.27	2.05
C	3.16	2.99
D	3.04	2.23
Flow Rate, cu.m/d		
A	9,084	5,034
B	12,377	7,759
C	11,961	11,317
D	11,506	8,441
Flow Rate, mgd		
A & B	5.67	3.38
C & D	6.20	5.22
Flow Rate, cu.m/d		
A & B	21,461	12,793
C & D	23,467	19,758
Suspended Solids, mg/l	78	112
Volatile Suspended Solids, mg/l	59	88
BOD, mg/l	90	124
NH4-N, mg/l	12.1	16.0
AERATION BATTERIES		
HRT, Hours		
A	7.7	11.1
B	8.3	10.1
C	8.9	11.0
D	8.9	11.0
SRT, Days		
A	4.7	5.5
B	14.9	12.8
C	11.8	10.8
D	11.3	8.7
SLUDGE VOLUME INDEX (SVI)		
A	72	70
B	75	82
C	85	91
D	90	88

APPENDIX TABLE D-3
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3b

	1987	
	AUG	SEP
MLSS, mg/L		
A	2,972	3,005
B	2,699	2,547
C	3,104	2,909
D	2,986	2,308
MLVSS, mg/l		
A	2,115	2,092
B	1,912	1,807
C	2,185	2,018
D	2,108	1,952
BOD, mg/L		
Raw Sewage	90	124
Primary Effluent		
A & B	72	77
C & D	79	101
Secondary Effluent		
A & B	3	3
C & D	2	3
PERCENT REMOVAL		
A & B	96.7	97.6
C & D	97.8	97.6
Suspended Solids, mg/L		
Raw Sewage	78	112
Primary Effluent		
A & B	70	60
C & D	72	87
PERCENT REMOVAL		
A & B	63.1	78.0
C & D	57.9	62.4
Secondary Effluent		
A & B	6	5
C & D	5	5
PERCENT REMOVAL		
A & B	92.3	95.5
C & D	93.6	95.5

APPENDIX TABLE D-3
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3b

	1987	
	AUG	SEP
NH4-N, mg/L		
Raw Sewage	12.1	16.0
Primary Effluent		
A & B	9.6	13.9
C & D	11.3	15.6
Secondary Effluent		
A & B	0.2	0.5
C & D	0.2	0.3
PERCENT REMOVAL		
A & B	98.3	96.9
C & D	98.3	98.1
RETURNED & WASTED SLUDGE		
Flow Rate Returned, mgd		
A	1.28	0.92
B	2.65	1.78
C	2.28	1.61
D	2.30	1.64
Flow Rate Returned, cu.m/d		
A	4,845	3,482
B	10,030	6,737
C	8,630	6,094
D	8,706	6,207
Flow Rate Wasted, mgd		
A	0.056	0.058
B	0.036	0.036
C	0.037	0.039
D	0.033	0.040
Flow Rate Wasted, cu.m/d		
A	212	220
B	136	136
C	140	148
D	125	151

APPENDIX TABLE D-3
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3b

	1987	
	AUG	SEP
Flow Rate Returned, mgd		
A & B	3.93	2.70
C & D	6.58	3.25
Flow Rate Returned, cu.m/d		
A & B	14,875	10,220
C & D	17,335	12,301
Flow Rate Wasted, mgd		
A & B	0.092	0.094
C & D	0.070	0.079
Flow Rate Wasted, cu.m/d		
A & B	348	356
C & D	265	299
Suspended Solids, mg/l		
A	7,648	5,584
B	6,153	6,780
C	7,812	7,163
D	9,109	9,022
Volatile Suspended Solids, mg/l		
A	5,177	3,626
B	3,937	6,230
C	5,430	5,063
D	6,134	6,790
PRIMARY + WASTE ACTIVATED SLUDGE		
Sludge Flow Rate, gpd (From Holding Tank Levels)		
A	7,760	8,010
B	5,290	6,170
A & B	13,050	12,180
C & D	18,100	23,100
Sludge Flow Rate, cu.m/d (From Holding Tank Levels)		
A	29	30
B	20	16
C	69	66
D	69	87
Sludge Flow Rate, gpd (From Pump Strokes)		
A & B	10,500	19,400
C & D	18,900	23,500

APPENDIX TABLE D-3
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3b

	1987	
	AUG	SEP
Sludge Flow Rate, cu.m/d (From Pump Strokes)		
A & B	40	73
C & D	72	89
Total Solids, %		
A	2.89	2.92
B	3.75	3.39
A & B	3.24	3.08
C & D	3.27	2.63
Total Volatile Solids, %		
A	67.2	65.2
B	67.0	65.6
A & B	67.1	65.4
C & D	67.2	67.4
ANAEROBIC DIGESTER SLUDGE		
Sludge Feed Rate, gpd		
1	12,830	11,750
3	21,440	26,730
Sludge Feed Rate, cu.m/d		
1	49	44
3	81	101
Sludge Withdrawal Rate, gpd		
2	14,070	12,470
4	23,040	29,130
Sludge Withdrawal Rate, cu.m/d		
2	53	47
4	87	110
Sludge Recycle Rate: DIG # 4		
%	25.4	32.0
gpd	5,850	9,310
cu.m/d	22	35
Detention Time, Days		
1	11.8	12.9
2	10.7	12.1
3	7.3	5.8
4	6.8	5.4

APPENDIX TABLE D-3
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3b

	--------1987------	
	AUG	SEP
Total Solids, %		
1-Feed	3.24	3.08
1-Draw	2.15	2.19
2-Feed	2.15	2.19
2-Draw	1.80	1.90
3-Feed	3.27	2.63
3-Draw	1.99	1.78
4-Feed	1.99	1.78
4-Draw	1.71	1.70
Total Volatile Solids,%		
1-Feed	67.1	65.4
1-Draw	63.7	58.2
2-Feed	63.7	58.2
2-Draw	63.7	57.3
3-Feed	67.2	67.4
3-Draw	62.0	59.2
4-Feed	62.0	59.2
4-Draw	60.5	54.6
Total Solids In, lb/d		
1 & 2	3,465	3,019
3 & 4	5,847	5,863
Total Solids In, kg/d		
1 & 2	1,572	1,369
3 & 4	2,652	2,659
Total Solids Withdrawn, lb/d		
1 & 2	2,112	1,976
3 & 4	3,286	4,130
Total Solids Withdrawn, kg/d		
1 & 2	958	896
3 & 4	1,490	1,873
Total Solids Recycled: DIG # 4		
%	25.4	32.0
lb/d	834	1,320
kg/d	378	599
Total Solids Destroyed, lb/d		
1 & 2	1,353	1,043
3 & 4	2,561	1,733
Total Solids Destroyed, kg/d		
1 & 2	614	473
3 & 4	1,162	786

APPENDIX TABLE D-3
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3b

	1987	
	AUG	SEP
Total Solids Destroyed, %		
1 & 2	39.0	34.6
3 & 4	43.8	29.6
Volatile Solids In, lb/d		
1 & 2	2,325	1,973
3 & 4	3,929	3,952
Volatile Solids In, kg/d		
1 & 2	1,055	895
3 & 4	1,782	1,792
Volatile Solids Withdrawn, lb/d		
1 & 2	1,345	1,132
3 & 4	1,988	2,255
Volatile Solids Withdrawn, kg/d		
1 & 2	610	514
3 & 4	902	1,023
Volatile Solids Recycled: DIG # 4		
%	25.4	32.0
lb/d	505	721
kg/d	229	327
Volatile Solids Destroyed, lb/d		
1 & 2	980	841
3 & 4	1,941	1,697
Volatile Solids Destroyed, kg/d		
1 & 2	445	381
3 & 4	881	770
Volatile Solids Destroyed, %		
1 & 2	42.1	42.6
3 & 4	49.4	42.9
Gas Volume From Digesters cu.ft/d		
1	11,230	8,120
2	1,830	2,470
3	17,320	15,150
4	6,350	5,830
Gas Volume From Digesters cu.m/d		
1	318.03	229.96
2	51.83	69.95
3	490.50	429.05
4	179.83	165.11

APPENDIX TABLE D-3
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3b

	1987	
	AUG	SEP
Gas Production, cu.ft/lbs VS		
1	15.6	12.5
2	7.0	12.8
3	11.1	10.9
4	16.6	19.1
Gas Production, cu.m/kg VS		
1	0.98	0.78
2	0.44	0.80
3	0.69	0.68
4	1.04	1.19
Volatile Solids Loading Rate lbs/(cu.ft*d)		
1	0.12	0.10
2	0.08	0.07
3	0.19	0.19
4	0.11	0.12
Volatile Solids Loading Rate kg/(cu.m*d)		
1	1.85	1.57
2	1.28	1.05
3	3.02	3.04
4	1.82	1.97
Volatile Solids In, lb/d		
1	2,325	1,973
2	1,607	1,326
3	3,929	3,952
4	2,371	2,560
Volatile Solids In, kg/d		
1	1,055	895
2	729	601
3	1,782	1,792
4	1,075	1,161
Volatile Solids Destroyed, lb/d		
1	718	647
2	262	193
3	1,558	1,392
4	383	305

APPENDIX TABLE D-3
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3b

	1987	
	AUG	SEP
Volatile Solids Destroyed, kg/d		
1	326	294
2	119	88
3	707	631
4	174	138
Volatile Solids Destroyed, %		
1	30.9	32.8
2	16.3	14.6
3	39.7	35.2
4	16.1	11.9
pH		
1-Feed	6.1	6.3
1-Draw	7.2	7.2
2-Feed	7.2	7.2
2-Draw	7.3	7.3
3-Feed	5.9	6.1
3-Draw	7.2	7.1
4-Feed	7.2	7.1
4-Draw	7.7	7.6
Alkalinity, mg/L		
1-Feed	588	665
1-Draw	1,683	1,643
2-Feed	1,683	1,643
2-Draw	1,847	1,826
3-Feed	540	516
3-Draw	1,567	1,378
4-Feed	1,567	1,378
4-Draw	1,803	1,753
Volatile Acids, mg/L		
1-Feed	818	618
1-Draw	19	19
2-Feed	19	19
2-Draw	17	19
3-Feed	1,165	854
3-Draw	43	34
4-Feed	43	34
4-Draw	110	68

APPENDIX TABLE D-3
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3b

	--------1987------	
	AUG	SEP
NH4-N, mg/L		
1-Feed	115	133
1-Draw	377	374
2-Feed	377	374
2-Draw	422	422
3-Feed	109	129
3-Draw	325	299
4-Feed	325	299
4-Draw	449	415
TKN, mg/L		
1-Feed	1,406	1,408
1-Draw	1,273	1,250
2-Feed	1,273	1,250
2-Draw	1,228	1,228
3-Feed	1,387	1,335
3-Draw	1,139	1,064
4-Feed	1,139	1,064
4-Draw	1,125	1,046
Total COD, mg/L		
1-Feed	35,677	37,004
1-Draw	21,866	22,031
2=Feed	21,866	22,031
2-Draw	19,137	18,714
3-Feed	37,297	31,157
3-Draw	21,361	18,535
4-Feed	21,361	18,535
4-Draw	16,730	15,756
Soluble COD, mg/L		
1-Feed	1,532	1,259
1-Draw	351	282
2-Feed	351	282
2-Draw	256	242
3-Feed	1,802	1,600
3-Draw	254	224
4-Feed	254	224
4-Draw	669	386
REMOVAL Total COD, %		
1	38.7	40.5
2	12.5	15.1
3	42.7	40.5
4	21.7	15.0

APPENDIX TABLE D-3
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3b

	1987	
	AUG	SEP
REMOVAL Total COD, %		
1 & 2	46.4	49.4
3 & 4	55.1	49.4
REMOVAL Soluble COD, %		
1	77.1	77.6
2	27.1	14.2
3	85.9	86.0
4	-163.4	-72.3
REMOVAL Soluble COD, %		
1 & 2	83.3	80.8
3 & 4	62.9	75.9
THEORETICAL GAS PRODUCTION cu.ft/d		
1	13,396	13,301
2	2,903	3,127
3	25,831	25,507
4	8,067	6,120
THEORETICAL GAS PRODUCTION cu.m/d		
1	379.38	376.68
2	82.21	88.56
3	731.53	722.36
4	228.45	173.32
MEASURED GAS/THEORETICAL GAS		
1	0.838	0.610
2	0.630	0.790
3	0.671	0.594
4	0.787	0.953
COD Destroyed, lb/d		
1	1,478	1,467
2	320	345
3	2,850	2,814
4	890	675

APPENDIX TABLE D-3
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3b

	--------1987------	
	AUG	SEP
COD Destroyed, kg/d		
1	670	666
2	145	156
3	1,293	1,276
4	404	306
#VS DESTROYED/#COD DESTROYED		
1	0.486	0.441
2	0.817	0.560
3	0.547	0.495
4	0.430	0.452

APPENDIX TABLE D-4
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3c

	1987		1988
	NOV	DEC	JAN
RAW SEWAGE			
Flow Rate, mgd			
A	1.32	1.88	1.64
B	2.23	3.64	3.07
C	2.39	3.57	3.21
D	2.39	3.57	3.14
Flow Rate, cu.m/d			
A	4,996	7,116	6,207
B	8,441	13,777	11,620
C	9,046	13,512	12,150
D	9,046	13,512	11,885
Flow Rate, mgd			
A & B	3.55	5.52	4.71
C & D	4.78	7.14	6.35
Flow Rate, cu.m/d			
A & B	13,437	20,893	17,827
C & D	18,092	27,025	24,035
Suspended Solids, mg/l	109	74	90
Volatile Suspended Solids, mg/l	89	63	76
BOD, mg/l	128	91	106
NH4-N, mg/l	15.8	10.0	13.3
AERATION BATTERIES			
HRT, Hours			
A	10.9	7.9	9.1
B	11.7	7.1	8.8
C	10.7	7.2	8.2
D	10.7	7.2	8.4
SRT, Days			
A	5.3	5.0	7.3
B	12.5	11.3	9.8
C	10.2	8.9	10.0
D	10.7	8.5	11.1
SLUDGE VOLUME INDEX (SVI)			
A	69	80	75
B	79	79	106
C	101	109	134
D	105	111	120

APPENDIX TABLE D-4
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3c

	1987		1988
	NOV	DEC	JAN
MLSS, mg/L			
A	2,812	2,737	2,830
B	2,706	2,646	2,908
C	2,986	3,044	2,997
D	2,844	3,016	2,992
MLVSS, mg/l			
A	2,205	2,143	2,275
B	2,122	2,082	2,351
C	2,240	2,293	2,282
D	2,129	2,272	2,286
BOD, mg/L			
Raw Sewage	128	91	106
Primary Effluent			
A & B	88	59	73
C & D	99	87	93
Secondary Effluent			
A & B	6	11	10
C & D	4	5	10
PERCENT REMOVAL			
A & B	95.3	87.9	90.6
C & D	96.9	94.5	90.6
Suspended Solids, mg/L			
Raw Sewage	109	74	90
Primary Effluent			
A & B	76	36	48
C & D	75	64	70
PERCENT REMOVAL			
A & B	71.1	79.7	77.1
C & D	67.7	64.6	63.5
Secondary Effluent			
A & B	10	14	20
C & D	7	8	14
PERCENT REMOVAL			
A & B	90.8	81.1	77.8
C & D	93.6	89.2	84.4

APPENDIX TABLE D-4

MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3c

	1987		1988
	NOV	DEC	JAN
NH4-N, mg/L			
Raw Sewage	15.8	10.0	13.3
Primary Effluent			
A & B	14.0	6.6	11.6
C & D	15.2	9.7	12.4
Secondary Effluent			
A & B	0.6	1.0	0.8
C & D	0.5	0.2	2.8
PERCENT REMOVAL			
A & B	96.2	90.0	94.0
C & D	96.8	98.0	78.9
RETURNED & WASTED SLUDGE			
Flow Rate Returned, mgd			
A	0.92	1.25	1.14
B	1.61	2.55	2.21
C	1.70	2.51	2.29
D	1.70	2.51	2.29
Flow Rate Returned, cu.m/d			
A	3,482	4,731	4,315
B	6,094	9,652	8,365
C	6,435	9,500	8,668
D	6,435	9,500	8,668
Flow Rate Wasted, mgd			
A	0.058	0.059	0.042
B	0.040	0.038	0.051
C	0.045	0.046	0.047
D	0.034	0.046	0.040
Flow Rate Wasted, cu.m/d			
A	220	223	159
B	151	144	193
C	170	174	178
D	129	174	151

APPENDIX TABLE D-4
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3c

	1987		1988
	NOV	DEC	JAN
Flow Rate Returned, mgd			
A & B	2.53	3.80	3.35
C & D	3.40	5.02	4.58
Flow Rate Returned, cu.m/d			
A & B	9,576	14,383	12,680
C & D	12,869	19,001	17,335
Flow Rate Wasted, mgd			
A & B	0.098	0.097	0.093
C & D	0.079	0.092	0.087
Flow Rate Wasted, cu.m/d			
A & B	371	367	352
C & D	299	348	329
Suspended Solids, mg/l			
A	5,387	5,725	5,771
B	6,483	6,543	6,667
C	7,023	7,996	7,345
D	8,572	8,931	7,916
Volalile Suspended Solids, mg/l			
A	4,230	4,533	4,641
B	5,241	4,896	5,338
C	5,221	5,836	5,541
D	6,274	7,037	6,160
PRIMARY + WASTE ACTIVATED SLUDGE			
Sludge Flow Rate, gpd (From Holding Tank Levels)			
A	8,030	6,350	5,650
B	5,500	4,460	3,250
A & B	13,530	10,810	8,900
C & D	25,400	23,000	29,200
Sludge Flow Rate, cu.m/d (From Holding Tank Levels)			
A	30	24	21
B	21	17	12
C	51	41	34
D	96	87	111
Sludge Flow Rate, gpd (From Pump Strokes)			
A & B	17,500	15,000	17,700
C & D	26,900	22,700	30,800

APPENDIX TABLE D-4
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3c

	1987		1988
	NOV	DEC	JAN
Sludge Flow Rate, cu.m/d (From Pump Strokes)			
A & B	66	57	67
C & D	102	86	117
Total Solids, %			
A	2.67	2.94	3.11
B	2.89	4.24	3.72
A & B	2.76	3.48	3.33
C & D	2.67	2.94	2.76
Total Volatile Solids, %			
A	74.5	75.2	78.4
B	74.9	74.6	79.1
A & B	74.7	74.9	78.7
C & D	74.4	74.7	76.4
ANAEROBIC DIGESTER SLUDGE			
Sludge Feed Rate, gpd			
1	13,720	13,340	11,550
3	31,350	24,650	35,550
Sludge Feed Rate, cu.m/d			
1	52	50	44
3	119	93	135
Sludge Withdrawal Rate, gpd			
2	15,570	14,590	12,740
4	31,720	26,380	30,780
Sludge Withdrawal Rate, cu.m/d			
2	59	55	48
4	120	100	117
Sludge Recycle Rate: DIG # 4			
%	37.8	45.9	38.3
gpd	12,000	12,100	11,800
cu.m/d	45	46	45
Detention Time, Days			
1	11.0	11.3	13.1
2	9.7	10.3	11.9
3	5.0	6.3	4.4
4	4.9	5.9	5.1

APPENDIX TABLE D-4
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3c

	-------1987------		--1988--
	NOV	DEC	JAN
Total Solids, %			
1-Feed	2.76	3.48	3.33
1-Draw	1.63	2.39	2.10
2-Feed	1.63	2.39	2.10
2-Draw	1.36	1.98	1.72
3-Feed	2.67	2.94	2.76
3-Draw	1.67	1.96	1.92
4-Feed	1.67	1.96	1.92
4-Draw	1.45	1.67	1.75
Total Volatile Solids,%			
1-Feed	74.7	74.9	78.7
1-Draw	67.4	66.9	67.9
2-Feed	67.4	66.9	67.9
2-Draw	66.3	65.4	65.5
3-Feed	74.4	74.7	76.4
3-Draw	67.6	67.4	69.4
4-Feed	67.6	67.4	69.4
4-Draw	62.7	63.5	64.9
Total Solids In, lb/d			
1 & 2	3,157	3,868	3,210
3 & 4	6,981	6,044	8,183
Total Solids In, kg/d			
1 & 2	1,432	1,754	1,456
3 & 4	3,167	2,742	3,712
Total Solids Withdrawn, lb/d			
1 & 2	1,766	2,409	1,828
3 & 4	3,836	3,674	4,492
Total Solids Withdrawn, kg/d			
1 & 2	801	1,093	829
3 & 4	1,740	1,667	2,038
Total Solids Recycled: DIG # 4			
%	37.8	45.9	38.3
lb/d	1,451	1,685	1,722
kg/d	658	764	781
Total Solids Destroyed, lb/d			
1 & 2	1,391	1,458	1,383
3 & 4	3,145	2,370	3,691
Total Solids Destroyed, kg/d			
1 & 2	631	662	627
3 & 4	1,427	1,075	1,674

APPENDIX TABLE D-4
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3c

	1987		1988
	NOV	DEC	JAN
Total Solids Destroyed, %			
1 & 2	44.1	37.7	43.1
3 & 4	45.1	39.2	45.1
Volatile Solids In, lb/d			
1 & 2	2,358	2,897	2,526
3 & 4	5,194	4,515	6,252
Volatile Solids In, kg/d			
1 & 2	1,069	1,314	1,146
3 & 4	2,356	2,048	2,836
Volatile Solids Withdrawn, lb/d			
1 & 2	1,171	1,576	1,197
3 & 4	2,405	2,333	2,916
Volatile Solids Withdrawn, kg/d			
1 & 2	531	715	543
3 & 4	1,091	1,058	1,322
Volatile Solids Recycled: DIG # 4			
%	37.8	45.9	38.3
lb/d	910	1,070	1,118
kg/d	413	485	507
Volatile Solids Destroyed, lb/d			
1 & 2	1,187	1,321	1,329
3 & 4	2,789	2,182	3,336
Volatile Solids Destroyed, kg/d			
1 & 2	538	599	603
3 & 4	1,265	990	1,513
Volatile Solids Destroyed, %			
1 & 2	50.3	45.6	52.6
3 & 4	53.7	48.3	53.4
Gas Volume From Digesters			
cu.ft/d			
1	9,230	13,000	15,340
2	2,880	2,000	1,092
3	18,570	17,000	24,160
4	6,440	6,000	8,530
Gas Volume From Digesters			
cu.m/d			
1	261.39	368.16	434.43
2	81.56	56.64	30.93
3	525.90	481.44	684.21
4	182.38	169.92	241.57

APPENDIX TABLE D-4
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3c

	1987		1988
	NOV	DEC	JAN
Gas Production, cu.ft/lbs VS			
1	9.9	13.7	15.2
2	11.3	5.4	3.4
3	8.4	10.6	8.5
4	11.1	10.5	16.9
Gas Production, cu.m/kg VS			
1	0.62	0.85	0.95
2	0.70	0.34	0.21
3	0.53	0.66	0.53
4	0.69	0.65	1.05
Volatile Solids Loading Rate lbs/(cu.ft*d)			
1	0.12	0.14	0.13
2	0.07	0.10	0.08
3	0.25	0.22	0.30
4	0.14	0.14	0.16
Volatile Solids Loading Rate kg/(cu.m*d)			
1	1.87	2.30	2.00
2	1.13	1.54	1.20
3	3.99	3.47	4.80
4	2.29	2.23	2.63
Volatile Solids In, lb/d			
1	2,358	2,897	2,526
2	1,427	1,946	1,515
3	5,194	4,515	6,252
4	2,986	2,906	3,421
Volatile Solids In, kg/d			
1	1,069	1,314	1,146
2	647	883	687
3	2,356	2,048	2,836
4	1,355	1,318	1,552
Volatile Solids Destroyed, lb/d			
1	931	951	1,011
2	256	370	318
3	2,207	1,609	2,831
4	581	573	505

APPENDIX TABLE D-4
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3c

	1987		1988
	NOV	DEC	JAN
Volatile Solids Destroyed, kg/d			
1	422	431	459
2	116	168	144
3	1,001	730	1,284
4	264	260	229
Volatile Solids Destroyed, %			
1	39.5	32.8	40.0
2	17.9	19.0	21.0
3	42.5	35.6	45.3
4	19.5	19.7	14.8
pH			
1-Feed	6.3	5.9	5.7
1-Draw	7.2	7.3	7.3
2-Feed	7.2	7.3	7.3
2-Draw	7.3	7.3	7.4
3-Feed	6.1	6.0	6.0
3-Draw	7.2	7.2	7.0
4-Feed	7.2	7.2	7.0
4-Draw	7.6	7.7	7.6
Alkalinity, mg/L			
1-Feed	725	976	910
1-Draw	1,600	2,093	2,709
2-Feed	1,600	2,093	2,709
2-Draw	1,665	2,158	2,640
3-Feed	652	718	704
3-Draw	1,426	1,697	1,913
4-Feed	1,426	1,697	1,913
4-Draw	1,753	2,220	2,730
Volatile Acids, mg/L			
1-Feed	649	1,826	1,788
1-Draw	67	59	44
2-Feed	67	59	44
2-Draw	17	22	29
3-Feed	859	1,089	981
3-Draw	47	43	215
4-Feed	47	43	215
4-Draw	104	105	333

APPENDIX TABLE D-4
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3c

	1987		1988
	NOV	DEC	JAN
NH4-N, mg/L			
1-Feed	121	157	199
1-Draw	334	401	629
2-Feed	334	401	629
2-Draw	361	455	590
3-Feed	104	109	132
3-Draw	284	342	383
4-Feed	284	342	383
4-Draw	430	444	568
TKN, mg/L			
1-Feed	1,294	1,605	1,879
1-Draw	1,111	1,471	1,721
2-Feed	1,111	1,471	1,721
2-Draw	1,041	1,480	1,432
3-Feed	1,213	1,539	1,504
3-Draw	1,078	1,269	1,361
4-Feed	1,078	1,269	1,361
4-Draw	1,056	1,213	1,382
Total COD, mg/L			
1-Feed	31,053	41,945	41,442
1-Draw	18,176	30,924	22,913
2=Feed	18,176	30,924	22,913
2-Draw	15,086	24,547	18,889
3-Feed	30,582	33,285	34,419
3-Draw	18,412	21,876	22,601
4-Feed	18,412	21,876	22,601
4-Draw	15,321	17,950	18,219
Soluble COD, mg/L			
1-Feed	1,361	3,490	3,603
1-Draw	411	269	461
2-Feed	411	269	461
2-Draw	220	260	324
3-Feed	1,621	2,083	2,231
3-Draw	256	242	451
4-Feed	256	242	451
4-Draw	514	597	1,038
REMOVAL Total COD, %			
1	41.5	26.3	44.7
2	17.0	20.6	17.6
3	39.8	34.3	34.3
4	16.8	17.9	19.4

APPENDIX TABLE D-4
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3c

	1987		1988
	NOV	DEC	JAN
REMOVAL Total COD, %			
1 & 2	51.4	41.5	54.4
3 & 4	49.9	46.1	47.1
REMOVAL Soluble COD, %			
1	69.8	92.3	87.2
2	46.5	3.3	29.7
3	84.2	88.4	79.8
4	-100.8	-146.7	-130.2
REMOVAL Soluble COD, %			
1 & 2	83.8	92.6	91.0
3 & 4	68.3	71.3	53.5
THEORETICAL GAS PRODUCTION cu.ft/d			
1	13,357	11,115	16,180
2	3,637	7,034	3,876
3	28,844	21,262	31,763
4	7,413	7,830	10,197
THEORETICAL GAS PRODUCTION cu.m/d			
1	378.26	314.78	458.21
2	103.01	199.20	109.76
3	816.87	602.13	899.52
4	209.92	221.74	288.78
MEASURED GAS/THEORETICAL GAS			
1	0.691	1.170	0.948
2	0.792	0.284	0.282
3	0.644	0.800	0.761
4	0.869	0.766	0.837
COD Destroyed, lb/d			
1	1,473	1,226	1,785
2	401	776	428
3	3,182	2,345	3,504
4	818	864	1,125

APPENDIX TABLE D-4
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3c

	1987		1988
	NOV	DEC	JAN
COD Destroyed, kg/d			
1	668	556	810
2	182	352	194
3	1,443	1,064	1,589
4	371	392	510
#VS DESTROYED/#COD DESTROYED			
1	0.632	0.776	0.566
2	0.637	0.477	0.744
3	0.694	0.686	0.808
4	0.711	0.664	0.449

APPENDIX TABLE D-5
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3d

	1988				
	APR	MAY	JUN	JUL	AUG
RAW SEWAGE					
Flow Rate, mgd					
A	1.74	1.14	0.97	1.06	1.30
B	3.13	1.98	1.88	1.85	1.75
C	3.03	2.19	2.04	2.03	2.36
D	3.03	2.19	2.04	2.03	2.36
Flow Rate, cu.m/d					
A	6,586	4,315	3,671	4,012	4,921
B	11,847	7,494	7,116	7,002	6,624
C	11,469	8,289	7,721	7,684	8,933
D	11,469	8,289	7,721	7,684	8,933
Flow Rate, mgd					
A & B	4.87	3.12	2.85	2.91	3.05
C & D	6.06	4.38	4.08	4.06	4.72
Flow Rate, cu.m/d					
A & B	18,433	11,809	10,787	11,014	11,544
C & D	22,937	16,578	15,443	15,367	17,865
Suspended Solids, mg/l	99	128	74	78	86
Volatile Suspended Solids, mg/l	81	104	60	62	67
BOD, mg/l	102	149	142	119	116
NH4-N, mg/l	12.1	20.4	19.9	18.1	17.6
AERATION BATTERIES					
HRT, Hours					
A	8.8	12.0	14.8	13.0	10.8
B	9.1	12.5	13.1	13.7	15.4
C	8.7	11.3	12.1	12.2	10.8
D	8.7	11.3	12.1	12.2	10.8
SRT, Days					
A	6.4	8.3	8.1	5.4	4.9
B	17.8	27.0	31.6	21.7	18.8
C	7.9	8.1	7.9	6.7	6.0
D	6.1	8.2	6.9	5.4	5.3
SLUDGE VOLUME INDEX (SVI)					
A	62	77	137	97	121
B	88	86	103	104	100
C	76	74	73	75	98
D	91	85	80	71	75

APPENDIX TABLE D-5
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3d

	1988				
	APR	MAY	JUN	JUL	AUG
MLSS, mg/L					
A	2,662	2,734	2,772	2,761	2,800
B	2,365	2,370	2,447	2,230	3,244
C	2,765	2,817	2,805	2,649	2,636
D	2,585	2,695	2,704	2,497	2,536
MLVSS, mg/l					
A	2,060	2,191	2,213	2,223	2,194
B	1,818	1,889	1,967	1,789	2,498
C	2,013	2,060	2,046	1,922	1,908
D	1,895	1,981	1,991	1,810	1,835
BOD, mg/L					
Raw Sewage	102	149	142	119	116
Primary Effluent					
A & B	61	89	115	82	75
C & D	93	124	118	114	102
Secondary Effluent					
A & B	9	8	5	4	3
C & D	6	5	4	4	3
PERCENT REMOVAL					
A & B	91.2	94.6	96.5	96.6	97.4
C & D	94.1	96.6	97.2	96.6	97.4
Suspended Solids, mg/L					
Raw Sewage	99	128	74	78	86
Primary Effluent					
A & B	48	55	57	54	45
C & D	87	104	67	76	78
PERCENT REMOVAL					
A & B	73.1	75.1	68.0	75.5	80.3
C & D	62.1	64.7	74.6	74.2	72.6
Secondary Effluent					
A & B	18	15	9	9	5
C & D	8	5	5	6	3
PERCENT REMOVAL					
A & B	81.8	88.3	87.8	88.5	94.2
C & D	91.9	96.1	93.2	92.3	96.5

APPENDIX TABLE D-5
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3d

	1988				
	APR	MAY	JUN	JUL	AUG
NH4-N, mg/L					
Raw Sewage	12.1	20.4	19.9	18.1	17.6
Primary Effluent					
A & B	11.3	17.4	16.9	14.8	14.4
C & D	12.1	18.7	19.3	17.2	17.0
Secondary Effluent					
A & B	0.4	0.6	0.4	0.5	0.7
C & D	0.2	0.4	0.6	0.5	0.5
PERCENT REMOVAL					
A & B	96.7	97.1	98.0	97.2	96.0
C & D	98.3	98.0	97.0	97.2	97.2
RETURNED & WASTED SLUDGE					
Flow Rate Returned, mgd					
A	1.11	0.81	0.71	0.75	0.93
B	2.23	1.39	1.33	1.32	1.23
C	2.16	1.55	1.46	1.46	1.66
D	2.16	1.55	1.43	1.46	1.66
Flow Rate Returned, cu.m/d					
A	4,201	3,066	2,687	2,839	3,520
B	8,441	5,261	5,034	4,996	4,656
C	8,176	5,867	5,526	5,526	6,283
D	8,176	5,867	5,413	5,526	6,283
Flow Rate Wasted, mgd					
A	0.044	0.041	0.044	0.059	0.065
B	0.029	0.023	0.018	0.029	0.022
C	0.056	0.061	0.059	0.071	0.078
D	0.055	0.046	0.050	0.065	0.070
Flow Rate Wasted, cu.m/d					
A	167	155	167	223	246
B	110	87	68	110	83
C	212	231	223	269	295
D	208	174	189	246	265

APPENDIX TABLE D-5
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3d

	1988				
	APR	MAY	JUN	JUL	AUG
Flow Rate Returned, mgd					
A & B	3.34	2.20	2.04	2.07	2.16
C & D	4.32	3.10	2.89	2.92	3.32
Flow Rate Returned, cu.m/d					
A & B	12,642	8,327	7,721	7,835	8,176
C & D	16,351	11,734	10,939	11,052	12,566
Flow Rate Wasted, mgd					
A & B	0.073	0.064	0.062	0.088	0.087
C & D	0.111	0.107	0.109	0.136	0.148
Flow Rate Wasted, cu.m/d					
A & B	276	242	235	333	329
C & D	420	405	413	515	560
Suspended Solids, mg/l					
A	5,701	4,723	4,979	5,024	5,404
B	5,188	4,759	4,892	4,781	4,643
C	6,676	6,404	6,397	6,029	6,035
D	8,017	8,043	8,544	7,573	7,275
Volalile Suspended Solids, mg/l					
A	4,290	3,973	3,984	4,045	4,234
B	4,044	4,260	3,887	3,836	3,575
C	5,056	5,018	4,558	4,374	4,368
D	5,858	6,074	5,903	5,489	5,473
PRIMARY + WASTE ACTIVATED SLUDGE					
Sludge Flow Rate, gpd (From Holding Tank Levels)					
A	7,470	6,580	10,220	13,580	15,020
B	3,740	4,610	3,410	4,120	4,750
A & B	11,210	11,190	13,630	17,700	19,770
C & D	26,100	31,900	29,000	33,610	35,730
Sludge Flow Rate, cu.m/d (From Holding Tank Levels)					
A	28	25	39	51	57
B	14	17	13	16	18
C	42	42	52	67	75
D	99	121	110	127	135
Sludge Flow Rate, gpd (From Pump Strokes)					
A & B	16,400	14,100	16,500	19,910	18,590
C & D	27,300	33,200	28,400	36,440	39,820

APPENDIX TABLE D-5
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3d

	1988				
	APR	MAY	JUN	JUL	AUG
Sludge Flow Rate, cu.m/d (From Pump Strokes)					
A & B	62	53	62	75	70
C & D	103	126	107	138	151
Total Solids, %					
A	3.82	3.19	2.72	2.58	2.40
B	4.68	3.78	3.24	2.88	2.29
A & B	4.11	3.43	2.85	2.65	2.37
C & D	3.37	2.77	2.81	2.87	3.36
Total Volatile Solids, %					
A	76.4	78.0	78.5	76.2	72.5
B	77.1	79.0	79.4	76.8	73.0
A & B	76.7	78.5	78.8	76.4	72.6
C & D	73.5	73.0	73.1	71.0	68.4
ANAEROBIC DIGESTER SLUDGE					
Sludge Feed Rate, gpd					
1	12,160	10,200	12,530	14,190	14,550
3	31,020	34,700	28,970	33,140	37,870
Sludge Feed Rate, cu.m/d					
1	46	39	47	54	55
3	117	131	110	125	143
Sludge Withdrawal Rate, gpd					
2	14,700	13,990	15,400	17,150	17,000
4	33,520	40,080	32,010	39,540	43,365
Sludge Withdrawal Rate, cu.m/d					
2	56	53	58	65	64
4	127	152	121	150	164
Sludge Recycle Rate: DIG # 4					
%	54.3	48.9	60.8	49.4	43.3
gpd	18,200	19,600	19,460	19,540	18,775
cu.m/d	69	74	74	74	71
Detention Time, Days					
1	12.4	14.8	12.1	10.6	10.4
2	10.3	10.8	9.8	8.8	8.9
3	5.0	4.5	5.4	4.7	4.1
4	4.7	3.9	4.9	3.9	3.6

APPENDIX TABLE D-5
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3d

	1988				
	APR	MAY	JUN	JUL	AUG
Total Solids, %					
1-Feed	4.11	3.43	2.85	2.65	2.37
1-Draw	2.37	2.15	1.89	1.77	1.73
2-Feed	2.37	2.15	1.89	1.77	1.73
2-Draw	1.50	1.30	1.38	1.34	1.57
3-Feed	3.37	2.77	2.81	2.87	3.36
3-Draw	2.14	1.95	2.05	2.06	2.14
4-Feed	2.14	1.95	2.05	2.06	2.14
4-Draw	1.85	1.70	1.73	1.86	1.91
Total Volatile Solids,%					
1-Feed	76.7	78.5	78.8	76.4	72.6
1-Draw	66.8	66.6	68.7	69.6	66.8
2-Feed	66.8	66.6	68.7	69.6	66.8
2-Draw	64.2	61.5	64.0	65.0	62.3
3-Feed	73.5	73.0	73.1	71.0	68.4
3-Draw	65.6	66.4	66.4	65.9	64.7
4-Feed	65.6	66.4	66.4	65.9	64.7
4-Draw	62.6	63.0	63.2	63.9	61.4
Total Solids In, lb/d					
1 & 2	4,165	2,920	2,978	3,136	2,880
3 & 4	8,718	8,016	6,789	7,932	10,612
Total Solids In, kg/d					
1 & 2	1,889	1,325	1,351	1,422	1,306
3 & 4	3,955	3,636	3,080	3,598	4,814
Total Solids Withdrawn, lb/d					
1 & 2	1,839	1,517	1,772	1,917	2,226
3 & 4	5,172	5,683	4,618	6,134	6,908
Total Solids Withdrawn, kg/d					
1 & 2	834	688	804	869	1,010
3 & 4	2,346	2,578	2,095	2,782	3,133
Total Solids Recycled: DIG # 4					
%	54.3	48.9	60.8	49.4	43.3
lb/d	2,808	2,779	2,808	3,031	2,991
kg/d	1,274	1,261	1,274	1,375	1,357
Total Solids Destroyed, lb/d					
1 & 2	2,326	1,404	1,206	1,219	654
3 & 4	3,547	2,334	2,171	1,799	3,704
Total Solids Destroyed, kg/d					
1 & 2	1,055	637	547	553	297
3 & 4	1,609	1,059	985	816	1,680

APPENDIX TABLE D-5

MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3d

	1988				
	APR	MAY	JUN	JUL	AUG
Total Solids Destroyed, %					
1 & 2	55.8	48.1	40.5	38.9	22.7
3 & 4	40.7	29.1	32.0	22.7	34.9
Volatile Solids In, lb/d					
1 & 2	3,193	2,291	2,346	2,394	2,092
3 & 4	6,408	5,852	4,963	5,632	7,259
Volatile Solids In, kg/d					
1 & 2	1,448	1,039	1,064	1,086	949
3 & 4	2,907	2,654	2,251	2,555	3,293
Volatile Solids Withdrawn, lb/d					
1 & 2	1,181	933	1,134	1,266	1,387
3 & 4	3,238	3,580	2,919	3,919	4,241
Volatile Solids Withdrawn, kg/d					
1 & 2	536	423	515	565	629
3 & 4	1,469	1,624	1,324	1,778	1,924
Volatile Solids Recycled: DIG # 4					
%	54.3	48.9	60.8	49.4	43.3
lb/d	1,758	1,751	1,774	1,937	1,836
kg/d	797	794	805	879	833
Volatile Solids Destroyed, lb/d					
1 & 2	2,013	1,358	1,211	1,149	705
3 & 4	3,170	2,272	2,044	1,713	3,017
Volatile Solids Destroyed, kg/d					
1 & 2	913	616	549	521	320
3 & 4	1,438	1,031	927	777	1,369
Volatile Solids Destroyed, %					
1 & 2	63.0	59.3	51.6	48.0	33.7
3 & 4	49.5	38.8	41.2	30.4	41.6
Gas Volume From Digesters cu.ft/d					
1	17,730	16,950	11,920	12,486	9,335
2	1,677	1,145	3,200	1,891	2,639
3	24,050	23,990	24,710	20,788	17,960
4	6,740	8,510	7,670	7,879	7,155
Gas Volume From Digesters cu.m/d					
1	502.11	480.02	337.57	353.60	264.37
2	47.49	32.43	90.62	53.55	74.74
3	681.10	679.40	699.79	588.72	508.63
4	190.88	241.00	217.21	223.13	202.63

APPENDIX TABLE D-5
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3d

	1988				
	APR	MAY	JUN	JUL	AUG
Gas Production, cu.ft/lbs VS					
1	14.2	27.3	17.6	19.7	20.6
2	2.2	1.6	6.0	3.7	10.5
3	9.7	15.7	18.6	18.0	8.0
4	9.8	11.4	10.7	14.1	9.3
Gas Production, cu.m/kg VS					
1	0.88	1.71	1.10	1.23	1.29
2	0.14	0.10	0.37	0.23	0.65
3	0.60	0.98	1.16	1.12	0.50
4	0.61	0.71	0.67	0.88	0.58
Volatile Solids Loading Rate lbs/(cu.ft*d)					
1	0.16	0.11	0.12	0.12	0.10
2	0.10	0.08	0.08	0.09	0.08
3	0.31	0.28	0.26	0.27	0.35
4	0.19	0.21	0.17	0.21	0.26
Volatile Solids Loading Rate kg/(cu.m*d)					
1	2.53	1.82	1.86	1.90	1.66
2	1.56	1.33	1.32	1.40	1.30
3	6.92	6.49	3.81	6.33	5.58
4	3.01	3.32	2.79	3.66	3.85
Volatile Solids In, lb/d					
1	3,193	2,291	2,346	2,396	2,092
2	1,941	1,671	1,668	1,762	1,638
3	6,408	5,852	4,963	5,632	7,259
4	3,925	4,328	3,634	4,477	5,008
Volatile Solids In, kg/d					
1	1,448	1,039	1,064	1,086	949
2	880	758	756	799	743
3	2,907	2,654	2,251	2,555	3,293
4	1,780	1,963	1,648	2,031	2,271
Volatile Solids Destroyed, lb/d					
1	1,252	620	678	632	453
2	760	738	533	516	252
3	2,484	1,524	1,329	1,155	2,251
4	687	748	715	557	766

APPENDIX TABLE D-5

MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3d

	1988				
	APR	MAY	JUN	JUL	AUG
Volatile Solids Destroyed, kg/d					
1	568	281	308	287	206
2	345	335	262	234	114
3	1,127	691	603	524	1,021
4	312	339	324	253	348
Volatile Solids Destroyed, %					
1	39.2	27.1	28.9	26.4	21.7
2	39.2	44.2	32.0	29.3	15.4
3	38.8	26.0	26.8	20.5	31.0
4	17.5	17.3	19.7	12.4	15.3
pH					
1-Feed	5.6	5.4	5.3		
1-Draw	7.3	7.3	7.2		
2-Feed	7.3	7.3	7.2		
2-Draw	7.4	7.4	7.3		
3-Feed	5.8	5.8	5.6		
3-Draw	7.2	7.1	7.1		
4-Feed	7.2	7.1	7.1		
4-Draw	7.7	7.5	7.5		
Alkalinity, mg/L					
1-Feed	1,013	929	559		
1-Draw	2,934	3,052	2,217		
2-Feed	2,934	3,052	2,217		
2-Draw	2,203	2,413	2,203		
3-Feed	837	829	670		
3-Draw	1,961	1,791	1,711		
4-Feed	1,961	1,791	1,711		
4-Draw	2,350	2,269	1,941		
Volatile Acids, mg/L					
1-Feed	1,675	1,808	1,569		
1-Draw	52	86	155		
2-Feed	52	86	155		
2-Draw	19	53	186		
3-Feed	1,317	1,205	1,257		
3-Draw	70	180	163		
4-Feed	70	180	163		
4-Draw	216	166	318		

APPENDIX TABLE D-5
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3d

	1988				
	APR	MAY	JUN	JUL	AUG
NH_4-N, mg/L					
1-Feed	239	194	136		
1-Draw	724	751	586		
2-Feed	724	751	586		
2-Draw	555	605	575		
3-Feed	179	188	181		
3-Draw	474	414	405		
4-Feed	474	414	405		
4-Draw	478	575	563		
TKN, mg/L					
1-Feed	2,234	2,007	1,467		
1-Draw	1,886	1,951	1,511		
2-Feed	1,886	1,951	1,511		
2-Draw	1,324	1,268	1,252		
3-Feed	2,225	1,577	1,439		
3-Draw	1,425	1,332	1,344		
4-Feed	1,425	1,332	1,344		
4-Draw	1,455	1,374	1,308		
Total COD, mg/L					
1-Feed	48,369	45,795	38,956		
1-Draw	24,114	23,769	20,261		
2=Feed	24,114	23,769	20,261		
2-Draw	17,021	14,187	15,460		
3-Feed	35,465	37,636	36,177		
3-Draw	21,534	20,482	22,719		
4-Feed	21,534	20,482	22,719		
4-Draw	17,998	17,938	19,220		
Soluble COD, mg/L					
1-Feed	4,173	4,164	2,645		
1-Draw	362	305	415		
2-Feed	362	305	415		
2-Draw	242	237	371		
3-Feed	2,819	2,812	2,336		
3-Draw	271	383	360		
4-Feed	271	383	360		
4-Draw	750	608	711		
REMOVAL Total COD, %					
1	50.1	48.1	48.0		
2	29.4	40.3	23.7		
3	39.3	45.6	37.2		
4	16.4	12.4	15.4		

APPENDIX TABLE D-5

MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3d

	1988				
	APR	MAY	JUN	JUL	AUG
REMOVAL Total COD, %					
1 & 2	64.8	69.0	60.3		
3 & 4	49.3	52.3	46.9		
REMOVAL Soluble COD, %					
1	91.3	92.7	84.3		
2	33.1	22.3	10.6		
3	90.4	86.4	84.6		
4	-176.8	-58.7	-97.5		
REMOVAL Soluble COD, %					
1 & 2	94.2	94.3	86.0		
3 & 4	73.4	78.4	69.6		
THEORETICAL GAS PRODUCTION cu.ft/d					
1	22,298	17,001	17,710		
2	7,883	10,113	5,590		
3	32,671	45,002	29,476		
4	8,961	7,709	8,468		
THEORETICAL GAS PRODUCTION cu.m/d					
1	631.48	481.46	501.54		
2	223.24	286.41	158.30		
3	925.23	1274.45	834.75		
4	253.77	218.31	239.80		
MEASURED GAS/THEORETICAL GAS					
1	0.795	0.997	0.673		
2	0.213	0.113	0.572		
3	0.736	0.533	0.838		
4	0.752	1.104	0.906		
COD Destroyed, lb/d					
1	2,460	1,875	1,954		
2	870	1,116	617		
3	3,604	4,964	3,252		
4	989	850	934		

APPENDIX TABLE D-5
MONTHLY DATA OF CONTROL AND EXPERIMENTAL SECTIONS IN PHASE 3d

	1988				
	APR	MAY	JUN	JUL	AUG
COD Destroyed, kg/d					
1	1,116	851	886		
2	394	506	280		
3	1,635	2,252	1,475		
4	448	386	424		
#VS DESTROYED/#COD DESTROYED					
1	0.509	0.331	0.347		
2	0.874	0.661	0.865		
3	0.689	0.307	0.409		
4	0.695	0.880	0.765		

APPENDIX - E

SUMMARY DATA OF VARIOUS PHASES FOR THE CONTROL AND EXPERIMENTAL SECTIONS (ENGLISH AND METRIC UNITS)

APPENDIX TABLE E - 1
(ENGLISH AND METRIC UNITS)

APPENDIX TABLE E-1
SUMMARY DATA OF VARIOUS PHASES FOR CONTROL AND EXPERIMENTAL SECTIONS

	PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
RAW SEWAGE					
Flow Rate, mgd					
A	1.25	1.24	1.87	1.61	1.24
B	2.42	2.45	2.66	2.98	2.12
C	2.30	2.48	3.08	3.06	2.33
D	2.20	2.33	2.64	3.03	2.33
Flow Rate, cu.m/d					
A	4,725	4,684	7,059	6,106	4,701
B	9,168	9,283	10,068	11,279	8,017
C	8,697	9,377	11,639	11,569	8,819
D	8,336	8,829	9,973	11,481	8,819
Flow Rate, mgd					
A & B	3.66	3.69	4.53	4.59	3.36
C & D	4.48	5.06	5.71	6.09	4.66
Flow Rate, cu.m/d					
A & B	13,841	13,967	17,127	17,386	12,718
C & D	16,971	19,143	21,612	23,051	17,638
Suspended Solids, mg/l	87	90	95	91	93
Volatile Suspended Solids, mg/l	71	74	74	76	75
BOD, mg/l	126	119	107	108	126
NH_4-N, mg/l	17.6	16.1	14.1	13.0	17.6
AERATION BATTERIES					
HRT, Hours					
A	12.0	11.4	9.4	9.3	11.9
B	10.9	10.6	9.2	9.2	12.8
C	11.5	10.4	9.9	8.7	11.0
D	11.8	11.0	9.9	8.8	11.0
SRT, Days					
A	9.5	9.5	5.1	5.9	6.6
B	16.8	16.3	13.9	11.2	23.4
C	15.2	13.9	11.3	9.7	7.3
D	15.9	12.3	10.0	10.1	6.4
SLUDGE VOLUME INDEX (SVI)					
A	95	93	71	75	99
B	145	128	79	88	96
C	140	86	88	115	79
D	138	109	89	112	80

APPENDIX TABLE E-1
SUMMARY DATA OF VARIOUS PHASES FOR CONTROL AND EXPERIMENTAL SECTIONS

	PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
MLSS, mg/L					
A	2,675	2,932	2,989	2,793	2,746
B	2,434	2,724	2,623	2,753	2,531
C	2,719	2,958	3,007	3,009	2,734
D	2,634	2,896	2,647	2,951	2,603
MLVSS, mg/l					
A	2,119	2,361	2,104	2,208	2,176
B	1,894	2,163	1,860	2,185	1,992
C	2,143	2,332	2,102	2,272	1,990
D	2,070	2,278	2,030	2,229	1,902
BOD, mg/L					
Raw Sewage	126	119	107	108	126
Primary Effluent					
A & B	102	76	75	73	84
C & D	115	94	90	93	110
Secondary Effluent					
A & B	7	5	3	9	6
C & D	4	5	3	6	4
PERCENT REMOVAL					
A & B	94.8	95.8	97.2	91.7	95.4
C & D	96.5	96.2	97.7	94.2	96.5
Suspended Solids, mg/L					
Raw Sewage	87	90	95	91	93
Primary Effluent					
A & B	65	50	65	53	52
C & D	73	64	80	70	82
PERCENT REMOVAL					
A & B	64.0	73.9	71.1	75.0	74.3
C & D	58.3	65.3	60.3	65.2	69.6
Secondary Effluent					
A & B	9	8	6	15	11
C & D	6	6	5	10	5
PERCENT REMOVAL					
A & B	89.8	91.7	94.2	83.9	88.0
C & D	93.6	93.4	94.7	89.4	94.2

APPENDIX TABLE E-1

SUMMARY DATA OF VARIOUS PHASES FOR CONTROL AND EXPERIMENTAL SECTIONS

	PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
NH4-N, mg/L					
Raw Sewage	17.6	16.1	14.1	13.0	17.6
Primary Effluent					
A & B	14.5	12.4	11.7	10.7	15.0
C & D	16.4	15.0	13.4	12.4	16.9
Secondary Effluent					
A & B	0.6	0.6	0.4	0.8	0.5
C & D	0.3	0.4	0.3	1.2	0.4
PERCENT REMOVAL					
A & B	96.9	96.4	97.5	93.9	97.0
C & D	98.6	97.7	98.2	91.0	97.5
RETURNED & WASTED SLUDGE					
Flow Rate Returned, mgd					
A	0.88	0.90	1.10	1.10	0.86
B	1.78	1.77	2.22	2.12	1.50
C	1.63	1.76	1.95	2.17	1.66
D	1.63	1.68	1.97	2.17	1.65
Flow Rate Returned, cu.m/d					
A	3,322	3,416	4,164	4,176	3,263
B	6,723	6,681	8,384	8,037	5,678
C	6,184	6,662	7,362	8,201	6,276
D	6,164	6,359	7,456	8,201	6,253
Flow Rate Wasted, mgd					
A	0.036	0.033	0.057	0.053	0.051
B	0.032	0.032	0.036	0.043	0.024
C	0.032	0.032	0.038	0.046	0.065
D	0.027	0.032	0.037	0.040	0.057
Flow Rate Wasted, cu.m/d					
A	138	125	216	201	192
B	120	120	136	163	92
C	121	121	144	174	246
D	102	120	138	151	217

APPENDIX TABLE E-1
SUMMARY DATA OF VARIOUS PHASES FOR CONTROL AND EXPERIMENTAL SECTIONS

	PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
Flow Rate Returned, mgd					
A & B	2.65	2.67	3.32	3.23	2.36
C & D	3.26	3.44	3.92	4.33	3.31
Flow Rate Returned, cu.m/d					
A & B	10,045	10,096	12,547	12,213	8,940
C & D	12,348	13,020	14,818	16,402	12,528
Flow Rate Wasted, mgd					
A & B	0.068	0.065	0.093	0.096	0.075
C & D	0.059	0.064	0.075	0.086	0.122
Flow Rate Wasted, cu.m/d					
A & B	257	245	352	363	283
C & D	223	241	282	326	463
Suspended Solids, mg/l					
A	5,011	5,650	6,616	5,628	5.166
B	5,315	6,083	6,467	6,564	4,853
C	6,447	6,617	7,488	7,455	6,308
D	7,435	8,456	9,066	8,473	7,890
Volalile Suspended Solids, mg/l					
A	4,059	4,572	4,402	4,468	4,105
B	4,242	4,838	4,084	5,158	3,920
C	5,168	5,549	5,247	5,533	4,675
D	5,947	6,674	6,462	6,490	5,759
PRIMARY + WASTE ACTIVATED SLUDGE					
Sludge Flow Rate, gpd (From Holding Tank Levels)					
A	7,858	7,320	7,885	6,677	10,574
B	6,757	5,303	4,730	4,403	4,126
A & B	14,615	12,623	12,615	11,080	14,700
C & D	18,000	17,600	20,600	25,867	31,268
Sludge Flow Rate, cu.m/d (From Holding Tank Levels)					
A	30	28	30	25	40
B	26	20	18	17	16
C	55	48	48	42	56
D	68	67	78	98	118
Sludge Flow Rate, gpd (From Pump Strokes)					
A & B	15,454	13,750	14,950	16,733	17,100
C & D	18,738	18,250	21,200	26,800	33,032

APPENDIX TABLE E-1
SUMMARY DATA OF VARIOUS PHASES FOR CONTROL AND EXPERIMENTAL SECTIONS

	PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
Sludge Flow Rate, cu.m/d (From Pump Strokes)					
A & B	58	52	57	63	65
C & D	71	69	80	101	125
Total Solids, %					
A	2.72	2.91	2.91	2.91	2.94
B	2.88	3.66	3.57	3.62	3.37
A & B	2.79	3.22	3.15	3.19	3.06
C & D	2.95	3.40	2.95	2.79	3.04
Total Volatile Solids, %					
A	75.1	78.3	66.2	76.0	76.3
B	74.8	78.2	66.3	76.2	77.1
A & B	75.0	78.3	66.2	76.1	76.5
C & D	76.0	77.6	67.3	75.2	71.8
ANAEROBIC DIGESTER SLUDGE					
Sludge Feed Rate, gpd					
1	15,315	12,935	12,290	12,870	12,726
3	19,225	19,858	24,085	30,517	33,140
Sludge Feed Rate, cu.m/d					
1	58	49	47	49	48
3	73	75	91	116	125
Sludge Withdrawal Rate, gpd					
2	15,526	12,838	13,270	14,300	15,648
4	19,106	21,123	26,085	29,627	37,703
Sludge Withdrawal Rate, cu.m/d					
2	59	49	50	54	59
4	72	80	99	112	143
Sludge Recycle Rate: DIG # 4					
%	0.0	13.1	29.1	40.4	50.7
gpd	0	2,763	7,580	11,967	19,115
cu.m/d	0	10	29	45	72
Detention Time, Days					
1	9.9	11.7	12.3	11.7	11.9
2	9.7	11.8	11.4	10.6	9.6
3	8.1	7.9	6.5	5.1	4.7
4	8.2	7.4	6.0	5.3	4.1

APPENDIX TABLE E-1
SUMMARY DATA OF VARIOUS PHASES FOR CONTROL AND EXPERIMENTAL SECTIONS

	PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
Total Solids, %					
1-Feed	2.79	3.22	3.15	3.19	3.06
1-Draw	1.86	1.93	2.17	2.04	1.98
2-Feed	1.86	1.93	2.17	2.04	1.98
2-Draw	1.63	1.74	1.85	1.69	1.42
3-Feed	2.95	3.40	2.95	2.79	3.04
3-Draw	1.90	2.05	1.89	1.85	2.07
4-Feed	1.90	2.05	1.89	1.85	2.07
4-Draw	1.66	1.72	1.71	1.62	1.81
Total Volatile Solids,%					
1-Feed	75.0	78.3	66.2	76.1	76.5
1-Draw	66.4	69.1	61.0	67.4	67.7
2-Feed	66.4	69.1	61.0	67.4	67.7
2-Draw	64.6	67.4	60.5	65.7	63.4
3-Feed	76.0	77.6	67.3	75.2	71.8
3-Draw	66.7	68.3	60.6	68.1	65.8
4-Feed	66.7	68.3	60.6	68.1	65.8
4-Draw	61.8	64.2	57.6	63.7	62.8
Total Solids In, lb/d					
1 & 2	3,570	3,475	3,233	3,423	3,251
3 & 4	4,727	5,623	5,926	7,101	8,391
Total Solids In, kg/d					
1 & 2	1,619	1,576	1,467	1,553	1,475
3 & 4	2,144	2,550	2,688	3,221	3,806
Total Solids Withdrawn, lb/d					
1 & 2	2,115	1,860	2,047	2,012	1,851
3 & 4	2,639	3,030	3,709	4,011	5,691
Total Solids Withdrawn, kg/d					
1 & 2	959	844	929	912	839
3 & 4	1,197	1,374	1,682	1,819	2,582
Total Solids Recycled: DIG # 4					
%	0.0	13.1	29.1	40.4	50.7
lb/d	0	396	1,078	1,620	2,885
kg/d	0	180	489	735	1,309
Total Solids Destroyed, lb/d					
1 & 2	1,455	1,615	1,186	1,411	1,401
3 & 4	2,088	2,593	2,216	3,090	2,700
Total Solids Destroyed, kg/d					
1 & 2	660	733	538	640	635
3 & 4	947	1,176	1,005	1,402	1,225

APPENDIX TABLE E-1

SUMMARY DATA OF VARIOUS PHASES FOR CONTROL AND EXPERIMENTAL SECTIONS

	PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
Total Solids Destroyed, %					
1 & 2	40.8	46.5	36.7	41.2	43.1
3 & 4	44.2	46.1	37.4	43.5	32.2
Volatile Solids In, lb/d					
1 & 2	2,677	2,720	2,142	2,605	2,489
3 & 4	3,592	4,362	3,988	5,337	6,025
Volatile Solids In, kg/d					
1 & 2	1,214	1,234	971	1,182	1,129
3 & 4	1,629	1,978	1,809	2,421	2,733
Volatile Solids Withdrawn, lb/d					
1 & 2	1,365	1,253	1,239	1,322	1,173
3 & 4	1,631	1,944	2,135	2,555	3,575
Volatile Solids Withdrawn, kg/d					
1 & 2	619	569	562	600	532
3 & 4	740	882	968	1,159	1,622
Volatile Solids Recycled: DIG # 4					
%	0.0	13.1	29.1	40.4	50.7
lb/d	0	254	620	1,032	1,813
kg/d	0	115	281	468	822
Volatile Solids Destroyed, lb/d					
1 & 2	1,311	1,466	903	1,283	1,315
3 & 4	1,961	2,418	1,853	2,782	2,449
Volatile Solids Destroyed, kg/d					
1 & 2	595	665	410	582	597
3 & 4	889	1,097	841	1,262	1,111
Volatile Solids Destroyed, %					
1 & 2	49.0	53.9	42.2	49.2	52.9
3 & 4	54.6	55.4	46.5	52.1	40.7
Gas Volume From Digesters cu.ft/d					
1	14,621	15,573	9,675	12,523	13,684
2	1,735	3,063	2,150	1,991	2,110
3	15,367	26,098	16,235	19,910	22,300
4	2,798	6,880	6,090	6,990	7,591
Gas Volume From Digesters cu.m/d					
1	414.06	441.01	274.00	354.66	387.54
2	49.13	86.73	60.89	56.38	59.77
3	435.19	739.08	459.78	563.85	631.52
4	79.25	194.84	172.47	197.96	214.97

APPENDIX TABLE E-1
SUMMARY DATA OF VARIOUS PHASES FOR CONTROL AND EXPERIMENTAL SECTIONS

	PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
Gas Production, cu.ft/lbs VS					
1	13.6	12.1	16.3	13.0	18.6
2	7.4	17.6	9.6	6.3	3.7
3	9.8	13.7	10.8	9.0	12.8
4	7.2	13.3	17.4	12.5	10.8
Gas Production, cu.m/kg VS					
1	0.85	0.75	0.89	0.81	1.16
2	0.46	1.10	0.60	0.39	0.23
3	0.61	0.86	0.67	0.56	0.80
4	0.45	0.83	1.08	0.78	0.67
Volatile Solids Loading Rate lbs/(cu.ft*d)					
1	0.13	0.13	0.11	0.13	0.12
2	0.08	0.07	0.07	0.08	0.09
3	0.17	0.21	0.19	0.26	0.29
4	0.10	0.12	0.12	0.15	0.21
Volatile Solids Loading Rate kg/(cu.m*d)					
1	2.12	2.16	1.70	2.07	1.97
2	1.27	1.13	1.16	1.30	1.39
3	2.76	3.35	3.06	4.10	4.63
4	1.55	1.89	1.91	2.39	3.29
Volatile Solids In, lb/d					
1	2,677	2,720	2,142	2,605	2,489
2	1,599	1,427	1,464	1,640	1,751
3	3,592	4,362	3,988	5,337	6,025
4	2,020	2,461	2,485	3,114	4,279
Volatile Solids In, kg/d					
1	1,214	1,234	971	1,182	1,129
2	725	647	664	744	794
3	1,629	1,978	1,809	2,421	2,733
4	916	1,116	1,127	1,413	1,941
Volatile Solids Destroyed, lb/d					
1	1,077	1,292	678	965	738
2	234	174	225	318	578
3	1,572	1,900	1,503	2,223	1,746
4	389	518	350	559	703

APPENDIX TABLE E-1

SUMMARY DATA OF VARIOUS PHASES FOR CONTROL AND EXPERIMENTAL SECTIONS

	PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
Volatile Solids Destroyed, kg/d					
1	489	586	308	438	335
2	106	79	102	144	262
3	713	862	682	1,008	792
4	177	235	159	254	319
Volatile Solids Destroyed, %					
1	40.3	47.5	31.7	37.1	29.6
2	14.6	12.2	15.4	19.4	33.0
3	43.8	43.6	37.7	41.6	29.0
4	19.3	21.0	14.1	18.0	16.4
pH					
1-Feed	5.9	5.7	6.2	6.0	5.4
1-Draw	7.2	7.3	7.2	7.3	7.3
2-Feed	7.2	7.3	7.2	7.3	7.3
2-Draw	7.3	7.4	7.3	7.3	7.4
3-Feed	5.8	5.6	6.0	6.0	5.7
3-Draw	7.3	7.3	7.2	7.1	7.1
4-Feed	7.3	7.3	7.2	7.1	7.1
4-Draw	7.8	7.9	7.7	7.6	7.6
Alkalinity, mg/L					
1-Feed	854	757	627	870	834
1-Draw	2,138	2,426	1,663	2,134	2,734
2-Feed	2,061	2,426	1,663	2,134	2,734
2-Draw	2,376	2,634	1,837	2,154	2,273
3-Feed	736	773	528	691	779
3-Draw	2,139	2,263	1,473	1,679	1,821
4-Feed	2,139	2,263	1,473	1,679	1,821
4-Draw	2,486	2,600	1,778	2,234	2,187
Volatile Acids, mg/L					
1-Feed	828	1,768	718	1,421	1,617
1-Draw	98	46	19	57	98
2-Feed	98	46	19	57	98
2-Draw	77	27	18	23	86
3-Feed	1,218	1,474	1,010	976	1,260
3-Draw	78	655	39	102	138
4-Feed	78	32	39	102	138
4-Draw	205	193	89	181	233

APPENDIX TABLE E-1

SUMMARY DATA OF VARIOUS PHASES FOR CONTROL AND EXPERIMENTAL SECTIONS

	PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
NH4-N, mg/L					
1-Feed	181	156	124	159	190
1-Draw	508	589	376	455	687
2-Feed	654	588	376	455	687
2-Draw	522	655	422	469	578
3-Feed	162	179	119	115	183
3-Draw	482	536	312	336	431
4-Feed	482	536	312	336	431
4-Draw	651	717	432	487	605
TKN, mg/L					
1-Feed	1,327	1,627	1,407	1,593	1,903
1-Draw	1,301	1,605	1,262	1,434	1,783
2-Feed	1,224	1,558	1,262	1,434	1,783
2-Draw	1,297	1,552	1,228	1,318	1,281
3-Feed	1,404	1,757	1,361	1,419	1,767
3-Draw	1,365	1,616	1,102	1,236	1,367
4-Feed	1,365	1,616	1,102	1,236	1,367
4-Draw	1,331	1,532	1,086	1,217	1,379
Total COD, mg/L					
1-Feed	33,572	40,540	36,341	38,167	44,373
1-Draw	19,748	21,783	21,949	24,004	22,708
2=Feed	19,748	21,783	21,949	24,004	22,708
2-Draw	16,622	18,459	18,926	19,507	15,556
3-Feed	34,329	42,012	34,227	32,762	36,426
3-Draw	19,754	23,167	19,948	20,963	21,578
4-Feed	19,754	23,167	19,948	20,963	21,578
4-Draw	16,460	18,480	16,243	17,163	18,385
Soluble COD, mg/L					
1-Feed	2,554	2,909	1,396	2,818	3,661
1-Draw	281	327	317	380	361
2-Feed	281	363	317	380	361
2-Draw	227	295	269	268	283
3-Feed	2,539	2,753	1,701	1,978	2,656
3-Draw	232	278	239	316	338
4-Feed	231	278	239	316	338
4-Draw	724	944	528	716	690
REMOVAL Total COD, %					
1	41.2	46.3	39.6	37.1	48.8
2	15.8	15.3	13.8	18.7	31.5
3	42.5	44.9	41.7	36.0	40.8
4	16.7	20.2	18.6	18.1	14.8

APPENDIX TABLE E-1
SUMMARY DATA OF VARIOUS PHASES FOR CONTROL AND EXPERIMENTAL SECTIONS

	PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
REMOVAL Total COD, %					
1 & 2	50.5	54.5	67.9	68.9	64.9
3 & 4	52.1	56.0	52.5	47.6	49.5
REMOVAL Soluble COD, %					
1	89.0	88.8	77.3	86.5	90.1
2	19.4	18.6	21.3	29.5	21.4
3	90.9	89.9	85.9	84.0	87.3
4	-213.1	-239.4	-120.7	-126.4	-104.0
REMOVAL Soluble COD, %					
1 & 2	91.1	89.9	82.2	90.5	92.3
3 & 4	71.5	65.7	69.0	63.8	74.0
THEORETICAL GAS PRODUCTION cu.ft/d					
1	16,006	18,343	13,372	13,760	20,844
2	3,670	3,226	3,033	4,862	8,461
3	21,184	28,291	26,000	27,222	37,200
4	4,757	7,484	7,307	8,511	9,101
THEORETICAL GAS PRODUCTION cu.m/d					
1	453.28	519.48	378.70	389.70	590.32
2	103.92	91.36	85.89	137.68	239.61
3	599.93	801.20	736.33	770.92	1053.51
4	134.72	211.96	206.92	241.02	257.75
MEASURED GAS/THEORETICAL GAS					
1	0.913	0.849	0.724	0.910	0.656
2	0.473	0.949	0.709	0.409	0.249
3	0.725	0.922	0.624	0.731	0.599
4	0.588	0.919	0.833	0.821	0.834
COD Destroyed, lb/d					
1	1,766	2,024	1,475	1,518	2,299
2	405	356	335	536	933
3	2,337	3,121	2,868	3,003	4,104
4	525	826	806	939	1,004

APPENDIX TABLE E-1

SUMMARY DATA OF VARIOUS PHASES FOR CONTROL AND EXPERIMENTAL SECTIONS

	PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
COD Destroyed, kg/d					
1	801	918	669	689	1,043
2	184	161	152	263	623
3	1,060	1,416	1,301	1,362	1,861
4	238	375	366	426	455
#VS DESTROYED/#COD DESTROYED					
1	0.610	0.639	0.460	0.636	0.321
2	0.578	0.489	0.673	0.592	0.619
3	0.673	0.609	0.524	0.740	0.425
4	0.742	0.627	0.435	0.596	0.701

APPENDIX - F

MASS BALANCE OF SOLIDS AROUND VARIOUS UNITS OF CONTROL AND EXPERIMENTAL SECTIONS (METRIC UNITS)

APPENDIX TABLES F-1 THROUGH F-6
(METRIC UNITS)

APPENDIX TABLE F-1
MASS BALANCE OF VOLATILE SOLIDS AROUND SECONDARY SETTLING TANKS

		PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
kg MLVSS : A	IN	17,047	19,114	23,594	22,689	17,321
kg MLVSS : B	IN	30,082	34,510	34,293	42,184	27,267
kg MLVSS : C	IN	31,880	37,391	39,939	44,940	30,091
kg MLVSS : D	IN	30,000	34,591	35,393	43,899	28,727
kg VS SecEff : A	OUT	32	28	26	68	40
kg VS SecEff : B	OUT	63	55	39	129	70
kg VS SecEff : C	OUT	38	44	40	83	34
kg VS SecEff : D	OUT	36	41	38	83	34
kg VS RtnSlg : A	OUT	13,478	15,608	18,316	18,649	13,387
kg VS RtnSlg : B	OUT	28,504	32,300	34,217	41,435	22,246
kg VS RtnSlg : C	OUT	31,940	36,946	38,604	45,349	29,322
kg VS RtnSlg : D	OUT	36,639	42,413	48,158	53,198	35,994
kg VS WstSlg : A	OUT	559	571	949	896	786
kg VS WstSlg : B	OUT	507	581	556	839	359
kg VS WstSlg : C	OUT	624	672	754	963	1,150
kg VS WstSlg : D	OUT	606	802	892	982	1,246
kg MLVSS : A&B	IN	47,129	53,624	57,888	64,872	44,589
kg MLVSS : C&D	IN	61,880	71,982	75,333	88,838	58,818
kg VS SecEff : A&B	OUT	95	82	65	198	110
kg VS SecEff : C&D	OUT	74	85	78	166	68
kg VS RtnSlg : A&B	OUT	41,981	47,908	52,533	60,084	35,633
kg VS RtnSlg : C&D	OUT	68,579	79,359	86,762	98,547	65,315
kg VS WstSlg : A&B	OUT	1,066	1,152	1,505	1,735	1,145
kg VS WstSlg : C&D	OUT	1,230	1,473	1,646	1,965	2,396
kg VS SecEff+RtnSlg+WstSlg : A&B		43,143	49,142	54,104	62,017	36,888
kg MLVSS : A&B		47,129	53,624	57,888	64,872	44,589
% DIFFERENCE : A&B		8.5	8.4	6.5	4.4	17.3
kg VS SecEff+RtnSlg+WstSlg : C&D		69,883	80,917	88,487	100,658	67,779
kg MLVSS : C&D		61,880	71,982	75,333	88,838	58,818
% DIFFERENCE : C&D		-12.9	-12.4	-17.5	-13.3	-15.2

APPENDIX TABLE F-2

MASS BALANCE OF VOLATILE SOLIDS AROUND AERATION TANKS

		PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
kg MLVSS : A	OUT	17,047	19,116	23,594	22,689	17,321
kg MLVSS : B	OUT	30,082	34,510	34,293	42,184	27,267
kg MLVSS : C	OUT	31,880	37,379	39,909	44,888	30,020
kg MLVSS : D	OUT	30,000	34,579	35,364	43,848	28,658
kg VS RtnSlg : A	IN	13,478	15,608	18,316	18,649	13,387
kg VS RtnSlg : B	IN	28,504	32,300	34,217	41,435	22,246
kg VS RtnSlg : C	IN	31,940	36,966	38,604	45,349	29,322
kg VS RtnSlg : D	IN	36,639	42,613	48,158	53,198	35,994
kg VS PrimEff : A	IN	249	190	355	272	196
kg VS PrimEff : B	IN	483	377	506	502	334
kg VS PrimEff : C	IN	518	488	716	673	584
kg VS PrimEff : D	IN	497	459	613	668	584
kg VS DGDRAW : A	IN	0	0	0	0	0
kg VS DGDRAW : B	IN	0	0	0	0	0
kg VS DGDRAW : C	IN	0	58	141	234	411
kg VS DGDRAW : D	IN	0	58	141	234	411
kg MLVSS : A&B	OUT	47,129	53,624	57,888	64,872	44,589
kg MLVSS : C&D	OUT	61,880	71,958	75,273	88,736	58,677
kg VS RtnSlg : A&B	IN	41,981	47,908	52,533	60,084	35,633
kg VS RtnSlg : C&D	IN	68,579	79,359	86,762	98,547	65,315
kg VS PrimEff : A&B	IN	733	567	861	774	530
kg VS PrimEff : C&D	IN	1,015	947	1,329	1,340	1,168
kg VS DGDRAW : A&B	IN	0	0	0	0	0
kg VS DGDRAW : C&D	IN	0	115	281	468	822
kg MLVSS : A&B		47,129	53,624	57,888	64,872	44,589
kg VS RtnSlg+PrimEff+DGDRAW : A&B		42,714	48,475	53,394	60,858	36,163
% DIFFERENCE : A&B		-10.3	-10.6	-8.4	-6.6	-23.3
kg MLVSS : C&D		61,880	71,958	75,273	88,736	58,677
kg VS RtnSlg+PrimEff+DGDRAW : C&D		69,595	80,422	88,372	100,356	67,306
% DIFFERENCE : C&D		11.1	10.5	14.8	11.6	12.8

APPENDIX TABLE F-3

MASS BALANCE OF VOLATILE SOLIDS : AERATION & SECONDARY SETTLING TANKS

		PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
kg VS SecEff : A&B	OUT	95	82	65	198	110
kg VS SecEff : C&D	OUT	74	85	78	166	68
kg VS RtnSlg : A&B	OUT	41,981	47,908	52,533	60,084	35,633
kg VS RtnSlg : C&D	OUT	68,579	79,359	86,762	98,547	65,315
kg VS WstSlg : A&B	OUT	1,066	1,152	1,505	1,735	1,145
kg VS WstSlg : C&D	OUT	1,230	1,473	1,646	1,945	2,396
kg VS RtnSlg : A&B	IN	41,981	47,908	52,533	60,084	35,633
kg VS RtnSlg : C&D	IN	68,579	79,359	86,762	98,547	65,315
kg VS PrimEff : A&B	IN	733	567	861	774	530
kg VS PrimEff : C&D	IN	1,015	947	1,329	1,340	1,168
kg VS DGDRAW : A&B	IN	0	0	0	0	0
kg VS DGDRAW : C&D	IN	0	115	281	468	822
kg VS SecEff+RtnSlg+WstSlg : A&B		43,143	49,142	54,104	62,017	36,888
kg VS RtnSlg+PrimEff+DGDRAW : A&B		42,714	48,475	53,394	60,858	36,163
% DIFFERENCE		-1.0	-1.4	-1.3	-1.9	-2.0
kg VS SecEff+RtnSlg+WstSlg :C&D		69,883	80,917	88,487	100,658	67,779
kg VS RtnSlg+PrimEff+DGDRAW : C&D		69,595	80,422	88,372	100,356	67,306
% DIFFERENCE		-0.4	-0.6	-0.1	-0.3	-0.7

APPENDIX TABLE F-4
MASS BALANCE OF VOLATILE SOLIDS AROUND PRIMARY SETTLING TANKS

		PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
kg VS DGFEED : A	OUT	636	646	559	648	778
kg VS DGFEED : B	OUT	578	587	413	533	351
kg VS DGFEED : C	OUT	815	989	904	1,211	1,366
kg VS DGFEED : D	OUT	815	989	904	1,211	1,366
kg VS WstSlg : A	IN	559	571	949	896	786
kg VS WstSlg : B	IN	507	581	556	839	359
kg VS WstSlg : C	IN	624	672	754	963	1,150
kg VS WstSlg : D	IN	606	802	892	982	1,246
kg VS PrimEff : A	OUT	249	190	355	272	196
kg VS PrimEff : B	OUT	483	377	506	502	334
kg VS PrimEff : C	OUT	518	488	716	673	584
kg VS PrimEff : D	OUT	497	459	613	668	584
kg VS RAW : A	IN	336	346	519	464	351
kg VS RAW : B	IN	653	687	740	857	599
kg VS RAW : C	IN	619	694	855	879	659
kg VS RAW : D	IN	593	653	733	872	659
kg VS DGFEED : A&B	OUT	1,214	1,234	971	1,182	1,129
kg VS DGFEED : C&D	OUT	1,629	1,978	1,809	2,421	2,733
kg VS WstSlg : A&B	IN	1,066	1,152	1,505	1,735	1,145
kg VS WstSlg : C&D	IN	1,230	1,473	1,646	1,945	2,396
kg VS PrimEff : A&B	OUT	733	567	861	776	530
kg VS PrimEff : C&D	OUT	1,015	947	1,329	1,340	1,168
kg VS RAW : A&B	IN	989	1,033	1,258	1,321	951
kg VS RAW : C&D	IN	1,213	1,347	1,588	1,751	1,319

kg VS DGFEED : A&B	1,214	1,234	971	1,182	1,129
kg VS RAW+WstSlg-PrimEff : A&B	1,323	1,618	1,903	2,282	1,566
% DIFFERENCE : A&B	8.9	31.2	95.8	93.1	38.7
kg VS DGFEED : C&D	1,629	1,978	1,809	2,421	2,733
kg VS RAW+WstSlg-PrimEff : C&D	1,427	1,872	1,906	2,355	2,546
% DIFFERENCE : C&D	-12.4	-5.4	5.3	-2.7	-6.8

APPENDIX TABLE F-5
MASS BALANCE OF VOLATILE SOLIDS AROUND DIGESTERS

		PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
kg VS DGFEED : 1&2	IN	1,214	1,234	971	1,182	1,129
kg VS DGFEED : 3&4	IN	1,629	1,978	1,809	2,421	2,733
kg VS ToFarm : 1&2	OUT	619	569	562	600	532
kg VS ToFarm : 3&4	OUT	740	766	687	691	800
kg VS Recycle : 1&2	OUT	0	0	0	0	0
kg VS Recycle : 3&4	OUT	0	115	281	468	822
kg VS ToFarm+Recycle : 1&2		619	569	562	600	532
kg VS DGFEED : 1&2		1,214	1,234	971	1,182	1,129
% DIFFERENCE : 1&2	(% DESTROYED)	49.0	53.9	42.2	49.2	52.9
kg VS ToFarm+Recycle : 3&4		740	882	968	1,159	1,622
kg VS DGFEED : 3&4		1,629	1,978	1,809	2,421	2,733
% DIFFERENCE : 3&4	(% DESTROYED)	54.6	55.4	46.5	52.1	40.7

APPENDIX TABLE F-6
MASS BALANCE OF VOLATILE SOLIDS : PRIMARY SETTLING & AERATION TANKS

		PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
kg VS DGFEED : A&B	OUT	1,214	1,234	971	1,182	1,129
kg VS DGFEED : C&D	OUT	1,629	1,978	1,809	2,421	2,733
kg VS WstSlg : A&B	IN	1,066	1,152	1,505	1,735	1,145
kg VS WstSlg : C&D	IN	1,230	1,473	1,666	1,965	2,396
kg VS PrimEff : A&B	OUT	733	567	861	774	530
kg VS PrimEff : C&D	OUT	1,015	947	1,329	1,340	1,168
kg VS RAW : A&B	IN	989	1,033	1,258	1,321	951
kg VS RAW : C&D	IN	1,213	1,347	1,588	1,751	1,319
kg VS ToFarm : 1&2	OUT	619	569	562	600	532
kg VS ToFarm : 3&4	OUT	740	766	687	691	800
kg VS Recycle : 1&2	OUT	0	0	0	0	0
kg VS Recycle : 3&4	OUT	0	115	281	468	822
kg VS ToFarm+Recycle : 1&2		619	569	562	600	532
kg VS RAW+WstSlg-PrimEff : 1&2		1,323	1,618	1,903	2,282	1,566
% DIFFERENCE : 1&2 (% DESTROYED)		53.2	64.9	70.5	73.7	66.0
kg VS ToFarm+Recycle : 3&4		760	882	968	1,159	1,622
kg VS RAW+WstSlg-PrimEff : 3&4		1,427	1,872	1,906	2,355	2,546
% DIFFERENCE : 3&4 (% DESTROYED)		48.2	52.9	49.2	50.8	36.3

F-6 : 1

APPENDIX - G

MASS BALANCE OF SOLIDS AROUND VARIOUS UNITS OF CONTROL AND EXPERIMENTAL SECTIONS (ENGLISH UNITS)

APPENDIX TABLES G-1 THROUGH G-6
(ENGLISH UINITS)

APPENDIX TABLE G-1
MASS BALANCE OF VOLATILE SOLIDS AROUND SECONDARY SETTLING TANKS

		PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
LBS MLVSS : A	IN	37,581	42,138	52,016	50,019	38,187
LBS MLVSS : B	IN	66,319	76,081	75,603	92,998	60,113
LBS MLVSS : C	IN	70,282	82,433	88,050	99,073	66,339
LBS MLVSS : D	IN	66,139	76,258	78,028	96,779	63,330
LBS VS SecEff : A	OUT	71	61	58	151	88
LBS VS SecEff : B	OUT	138	120	85	285	154
LBS VS SecEff : C	OUT	84	97	89	184	75
LBS VS SecEff : D	OUT	80	91	83	183	75
LBS VS RtnSlg : A	OUT	29,713	34,409	40,379	41,114	29,513
LBS VS RtnSlg : B	OUT	62,838	71,208	75,435	91,347	69,044
LBS VS RtnSlg : C	OUT	70,615	81,450	85,105	99,975	64,642
LBS VS RtnSlg : D	OUT	80,774	93,504	106,169	117,280	79,351
LBS VS WstSlg : A	OUT	1,232	1,258	2,092	1,975	1,732
LBS VS WstSlg : B	OUT	1,119	1,281	1,226	1,850	791
LBS VS WstSlg : C	OUT	1,376	1,481	1,663	2,123	2,534
LBS VS WstSlg : D	OUT	1,335	1,767	1,967	2,165	2,748
LBS MLVSS : A&B	IN	103,900	118,219	127,618	143,017	98,299
LBS MLVSS : C&D	IN	136,421	158,690	166,077	195,852	129,669
LBS VS SecEff : A&B	OUT	210	181	144	436	242
LBS VS SecEff : C&D	OUT	164	187	172	366	150
LBS VS RtnSlg : A&B	OUT	92,552	105,617	115,814	132,461	78,557
LBS VS RtnSlg : C&D	OUT	151,189	174,954	191,274	217,256	143,993
LBS VS WstSlg : A&B	OUT	2,350	2,539	3,318	3,825	2,524
LBS VS WstSlg : C&D	OUT	2,711	3,268	3,630	4,288	5,282
LBS VS SecEff+RtnSlg+WstSlg : A&B		95,112	108,338	119,276	136,721	81,323
LBS MLVSS : A&B		103,900	118,219	127,618	143,017	98,299
% DIFFERENCE : A&B		8.5	8.4	6.5	4.4	17.3
LBS VS SecEff+RtnSlg+WstSlg : C&D		154,064	178,389	195,076	221,910	149,424
LBS MLVSS : C&D		136,421	158,690	166,077	195,852	129,669
% DIFFERENCE : C&D		-12.9	-12.4	-17.5	-13.3	-15.2

APPENDIX TABLE G-2
MASS BALANCE OF VOLATILE SOLIDS AROUND AERATION TANKS

		PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
LBS MLVSS : A	OUT	37,581	42,138	52,016	50,019	38,187
LBS MLVSS : B	OUT	66,319	76,081	75,603	92,998	60,113
LBS MLVSS : C	OUT	70,282	82,406	87,983	98,960	66,181
LBS MLVSS : D	OUT	66,139	76,232	77,964	96,667	63,178
LBS VS RtnSlg : A	IN	29,713	34,609	40,379	41,114	29,513
LBS VS RtnSlg : B	IN	62,838	71,208	75,435	91,347	69,044
LBS VS RtnSlg : C	IN	70,415	81,650	85,105	99,975	64,642
LBS VS RtnSlg : D	IN	80,774	93,504	106,169	117,280	79,351
LBS VS PrimEff : A	IN	549	419	782	599	632
LBS VS PrimEff : B	IN	1,066	830	1,116	1,107	736
LBS VS PrimEff : C	IN	1,163	1,076	1,577	1,683	1,288
LBS VS PrimEff : D	IN	1,095	1,013	1,352	1,672	1,288
LBS VS DGDRAW : A	IN	0	0	0	0	0
LBS VS DGDRAW : B	IN	0	0	0	0	0
LBS VS DGDRAW : C	IN	0	127	310	516	906
LBS VS DGDRAW : D	IN	0	127	310	516	906
LBS MLVSS : A&B	OUT	103,900	118,219	127,618	143,017	98,299
LBS MLVSS : C&D	OUT	136,421	158,637	165,947	195,627	129,359
LBS VS RtnSlg : A&B	IN	92,552	105,617	115,814	132,461	78,557
LBS VS RtnSlg : C&D	IN	151,189	174,954	191,274	217,256	143,993
LBS VS PrimEff : A&B	IN	1,615	1,249	1,898	1,706	1,167
LBS VS PrimEff : C&D	IN	2,238	2,089	2,929	2,955	2,576
LBS VS DGDRAW : A&B	IN	0	0	0	0	0
LBS VS DGDRAW : C&D	IN	0	254	620	1,032	1,813
LBS MLVSS : A&B		103,900	118,219	127,618	143,017	98,299
LBS VS RtnSlg+PrimEff+DGDRAW : A&B		94,167	106,867	117,712	134,167	79,724
% DIFFERENCE : A&B		-10.3	-10.6	-8.4	-6.6	-23.3
LBS MLVSS : C&D		136,421	158,637	165,947	195,627	129,359
LBS VS RtnSlg+PrimEff+DGDRAW : C&D		153,627	177,297	196,824	221,263	148,381
% DIFFERENCE : C&D		11.1	10.5	14.8	11.6	12.8

APPENDIX TABLE G-3
MASS BALANCE OF VOLATILE SOLIDS : AERATION & SECONDARY SETTLING TANKS

		PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.6%	PHASE: 3d %RECYCLE 50.7%
LBS VS SecEff : A&B	OUT	210	181	144	436	262
LBS VS SecEff : C&D	OUT	164	187	172	366	150
LBS VS RtnSlg : A&B	OUT	92,552	105,617	115,814	132,461	78,557
LBS VS RtnSlg : C&D	OUT	151,189	174,954	191,274	217,256	163,993
LBS VS WstSlg : A&B	OUT	2,350	2,539	3,318	3,825	2,526
LBS VS WstSlg : C&D	OUT	2,711	3,248	3,630	4,288	5,282
LBS VS RtnSlg : A&B	IN	92,552	105,617	115,814	132,461	78,557
LBS VS RtnSlg : C&D	IN	151,189	174,954	191,274	217,256	163,993
LBS VS PrimEff : A&B	IN	1,615	1,269	1,898	1,706	1,167
LBS VS PrimEff : C&D	IN	2,238	2,089	2,929	2,955	2,576
LBS VS DGDRAW : A&B	IN	0	0	0	0	0
LBS VS DGDRAW : C&D	IN	0	254	620	1,032	1,813
LBS VS SecEff+RtnSlg+WstSlg : A&B		95,112	108,338	119,276	136,721	81,323
LBS VS RtnSlg+PrimEff+DGDRAW : A&B		94,167	106,867	117,712	134,167	79,726
% DIFFERENCE		-1.0	-1.4	-1.3	-1.9	-2.0
LBS VS SecEff+RtnSlg+WstSlg :C&D		154,064	178,389	195,076	221,910	169,426
LBS VS RtnSlg+PrimEff+DGDRAW : C&D		153,427	177,297	194,826	221,263	168,381
% DIFFERENCE		-0.4	-0.6	-0.1	-0.3	-0.7

APPENDIX TABLE G-6
MASS BALANCE OF VOLATILE SOLIDS AROUND PRIMARY SETTLING TANKS

		PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
LBS VS DGFEED : A	OUT	1,403	1,425	1,232	1,429	1,714
LBS VS DGFEED : B	OUT	1,274	1,296	930	1,176	775
LBS VS DGFEED : C	OUT	1,796	2,181	1,994	2,669	3,012
LBS VS DGFEED : D	OUT	1,796	2,181	1,994	2,669	3,012
LBS VS WetSlg : A	IN	1,232	1,258	2,092	1,975	1,732
LBS VS WetSlg : B	IN	1,119	1,281	1,226	1,850	791
LBS VS WetSlg : C	IN	1,376	1,481	1,663	2,123	2,534
LBS VS WetSlg : D	IN	1,335	1,787	1,967	2,165	2,748
LBS VS PrimEff : A	OUT	549	419	782	599	432
LBS VS PrimEff : B	OUT	1,066	850	1,116	1,107	736
LBS VS PrimEff : C	OUT	1,143	1,076	1,577	1,483	1,288
LBS VS PrimEff : D	OUT	1,095	1,013	1,352	1,472	1,288
LBS VS RAW : A	IN	742	764	1,143	1,023	775
LBS VS RAW : B	IN	1,439	1,514	1,631	1,889	1,321
LBS VS RAW : C	IN	1,365	1,529	1,885	1,937	1,454
LBS VS RAW : D	IN	1,308	1,440	1,615	1,923	1,454
LBS VS DGFEED : A&B	OUT	2,677	2,720	2,162	2,605	2,489
LBS VS DGFEED : C&D	OUT	3,592	4,362	3,988	5,337	6,025
LBS VS WetSlg : A&B	IN	2,350	2,539	3,318	3,825	2,526
LBS VS WetSlg : C&D	IN	2,711	3,268	3,630	4,288	5,282
LBS VS PrimEff : A&B	OUT	1,615	1,269	1,898	1,706	1,167
LBS VS PrimEff : C&D	OUT	2,238	2,089	2,929	2,955	2,576
LBS VS RAW : A&B	IN	2,181	2,277	2,774	2,911	2,096
LBS VS RAW : C&D	IN	2,673	2,969	3,500	3,860	2,907

LBS VS DGFEED : A&B	2,677	2,720	2,162	2,605	2,489
LBS VS RAW+WetSlg-PrimEff : A&B	2,916	3,567	4,196	5,030	3,452
% DIFFERENCE : A&B	8.9	31.2	95.8	93.1	38.7
LBS VS DGFEED : C&D	3,592	4,362	3,988	5,337	6,025
LBS VS RAW+WetSlg-PrimEff : C&D	3,146	4,128	4,201	5,193	5,613
% DIFFERENCE : C&D	-12.4	-5.4	5.3	-2.7	-6.8

APPENDIX TABLE G-5
MASS BALANCE OF VOLATILE SOLIDS AROUND DIGESTERS

		PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
LBS VS DGFEED : 1&2	IN	2,677	2,720	2,142	2,605	2,489
LBS VS DGFEED : 3&4	IN	3,592	4,362	3,988	5,337	6,025
LBS VS ToFarm : 1&2	OUT	1,365	1,253	1,239	1,322	1,173
LBS VS ToFarm : 3&4	OUT	1,631	1,690	1,516	1,523	1,763
LBS VS Recycle : 1&2	OUT	0	0	0	0	0
LBS VS Recycle : 3&4	OUT	0	254	620	1,032	1,813

	PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
LBS VS ToFarm+Recycle : 1&2	1,365	1,253	1,239	1,322	1,173
LBS VS DGFEED : 1&2	2,677	2,720	2,142	2,605	2,489
% DIFFERENCE : 1&2 (% DESTROYED)	49.0	53.9	42.2	49.2	52.9
LBS VS ToFarm+Recycle : 3&4	1,631	1,944	2,136	2,555	3,575
LBS VS DGFEED : 3&4	3,592	4,362	3,988	5,337	6,025
% DIFFERENCE : 3&4 (% DESTROYED)	54.6	55.4	46.5	52.1	40.7

APPENDIX TABLE G-6
MASS BALANCE OF VOLATILE SOLIDS : PRIMARY SETTLING & AERATION TANKS

		PHASE: 2 %RECYCLE 0.0%	PHASE: 3a %RECYCLE 13.1%	PHASE: 3b %RECYCLE 29.1%	PHASE: 3c %RECYCLE 40.4%	PHASE: 3d %RECYCLE 50.7%
LBS VS DGFEED : A&B	OUT	2,677	2,720	2,142	2,605	2,489
LBS VS DGFEED : C&D	OUT	3,592	4,362	3,988	5,337	6,025
LBS VS WstSlg : A&B	IN	2,350	2,539	3,318	3,825	2,524
LBS VS WstSlg : C&D	IN	2,711	3,248	3,630	4,288	5,282
LBS VS PrimEff : A&B	OUT	1,615	1,249	1,898	1,706	1,167
LBS VS PrimEff : C&D	OUT	2,238	2,089	2,929	2,955	2,576
LBS VS RAW : A&B	IN	2,181	2,277	2,774	2,911	2,096
LBS VS RAW : C&D	IN	2,673	2,969	3,500	3,860	2,907
LBS VS ToFarm : 1&2	OUT	1,365	1,253	1,239	1,322	1,173
LBS VS ToFarm : 3&4	OUT	1,631	1,690	1,514	1,523	1,763
LBS VS Recycle : 1&2	OUT	0	0	0	0	0
LBS VS Recycle : 3&4	OUT	0	254	620	1,032	1,813
LBS VS ToFarm+Recycle : 1&2		1,365	1,253	1,239	1,322	1,173
LBS VS RAW+WstSlg-PrimEff : 1&2		2,916	3,567	4,194	5,030	3,452
% DIFFERENCE : 1&2 (% DESTROYED)		53.2	64.9	70.5	73.7	66.0
LBS VS ToFarm+Recycle : 3&4		1,631	1,944	2,135	2,555	3,575
LBS VS RAW+WstSlg-PrimEff : 3&4		3,146	4,128	4,201	5,193	7,613
% DIFFERENCE : 3&4 (% DESTROYED)		48.2	52.9	49.2	50.8	36.3

APPENDIX H

COMPUTATION OF VOLATILE SOLIDS MASS WITHDRAWN (CORRECTED) AND PERCENT VOLATILE SOLIDS DESTRUCTION (CORRECTED) FROM OBSERVED DATA

Appendix Table H-1 . Computation of Voaltile Solids Mass withdrawn (Corrected) and Percent Volatile Solids Destruction (Corrected) from Observed Data

Phase 2 Conditions (Reference Values).
Duration: 396 days
VS mass in Digesters 3 and 4: 13,561 kgs. (29,835 lbs.)
VS mass fed to Digester 3: 646,560 kgs. (1,422,432 lbs.)
VS mass withdrawn from Dig. 4: 293,580 kgs. (645,876 lbs.)
% VS destruction: 54.6

Phase 3a (Correction Sought)
VS mass in Digesters 3 and 4: 14,810 kgs.
Observed: (32,583 lbs.)
VS difference (Phase 3a - Phase 2 VS):
14,810 - 13,561 kgs. = 1,249 kgs = X
(32,583 - 29,835 = 2,748 lbs = X)
X = correction increment
VS mass fed during Phase 3a to Digester 3:
= 241,855 kgs.
= (532,080 lbs.)
VS mass withdrawn from Digester 4:
= 107,813 kgs.
= (237,188 lbs.)
Corrected VS mass withdrawn:
1,249 + 107,813 = 109,062 kgs.
(2,748 + 237,188 = 239,936 lbs.)
Observed % VS destruction:

$$\frac{241,855 - 107,813}{241,855 \text{ kgs.}} \text{ kgs.} \times 100$$

= 55.4

$$\frac{(\ 532,080 - 237,188}{(\ 532,080 \text{ lbs})} \text{ lbs.)} \times 100$$

= 55.4

Corrected % VS destruction:

$$\frac{241,855 - 109,062}{241,855 \text{ kgs.}} \text{ kgs.} \times 100$$

= 54.9

$$\frac{(\ 532,080 - 239,936}{(532,080)} \text{ lbs.)} \times 100$$

= 54.9

Equilibrium Phase 3b (Correction sought)
VS mass in Digesters 3 and 4 : 12,598 kgs.
Oberved: (27,715 lbs.)
VS difference: (Phase 3b VS - Phase 2 VS)
= 12,598 - 13,561 = -963 kgs.= Y
=(27,715 -29,835 = -2,120 lbs =Y)
VS mass fed to Digester 3 during Phase 3b:
= 110,576 kgs
(243,268 lbs.)

VS mass withdrawn form Digester 4:
= 59,198 kgs.
(130,235 lbs.)
Corrected VS mass withdrawn:
= 59,198 - 963 = 58,235 kgs.
=(130,235 - 2,120 = 128,115 lbs.)
Observed % VS Destruction:

$$\frac{110{,}576 - 59{,}198 \text{ kgs.}}{110{,}576} \times 100$$

= 46.5

$$\frac{(243{,}268 - 130{,}235 \text{ lbs.})}{(243{,}268) \text{ lbs.}} \times 100$$

= 46.5
Corrected % VS Destruction:

$$\frac{110{,}576 - 58{,}235 \text{ kgs.}}{110{,}576 \text{ kgs.}} \times 100$$

$$\frac{(243{,}268 - 128{,}115 \text{ lbs.})}{(\ 243{,}268)} \times 100$$

= 47.3